ON THE ABRASIVE FLOW MACHINING (AFM) PROCESS PERFORMANCE

by

SUNIL JHA

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR

APRIL, 1998

ON THE ABRASIVE FLOW MACHINING (AFM) PROCESS PERFORMANCE

A Thesis Submitted in
Partial Fulfillment of The Requirements
For The Degree Of

MASTER OF TECHNOLOGY

by

SUNIL JHA

to the

DEPARTMENT OF MECHANICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

APRIL, 1998

CERTIFICATE

It is certified that the work contained in the thesis entitled **"ON THE ABRASIVE FLOW MACHINING (AFM) PROCESS PERFORMANCE"** submitted by **Mr. Sunil Jha** is a bonafied research work carried out by him under our supervision and guidance This work has not been submitted elsewhere for a degree

Dr S K Chaudhary
Associate Professor,
Dept Of Mech Engg
I I T Kanpur

Dr V K Jain
Professor,
Dept Of Mech Engg
I I T Kanpur

April, 1998

ABSTRACT

Finishing and deburring operations in an overall manufacturing process are the most difficult, expensive and time absorbing elements and may constitute a significant part of the manufacturing cost The "Abrasive Flow machining(AFM)" process has a greater potential of being used to deburr, radius, polish, and remove recast layer of components in a wide range of applications In AFM, a semisolid viscoelastic abrasive laden media is made to flow over the selected surfaces of the workpiece

The major parts of AFM system are the machine, tooling and the abrasive laden media The tooling holds the workpiece and direct the flow of media through the restricted passage The AM process has vast application potential as it can finish inaccessible areas and complicated contours of the workpiece, and can finish many components simultaneously

The present work is an effort in the direction of understanding the AFM process performance For this, a hydraulically powered AFM set-up is designed and fabricated Few experiments are conducted on brass and aluminum samples, and the effects of different process parameters like number of cycles, extrusion pressure, and extrusion passage area on the material removal and surface finish are studied The machined surface is also analyzed under Scanning electron microscope (SEM)

The extrusion passage area effects the material removal significantly The material removed increases with the extrusion pressure and number of cycles For the same extrusion pressure and no of cycles the material removed is more in case of brass than aluminium In case of brass the surface finish improves with the increase in extrusion pressure, number of cycles and % passage area reduction As aluminium is softer material and samples are prepared by milling, the surface roughness increases with extrusion pressure and number of cycles because due to bigger grain size the abrasive marks appear on the surface and increase the Ra value The abrasive marks are clearly visible at higher magnification under scanning Electron Microscope

DEDICATED TO

GODDESS GAYATRI

&

GREAT GAYATRI MANTRA

ॐ

भूर्भुवः स्वः

तत्सवितुर्वरेण्यं

भर्गो देवस्य धीमहि।

धियो यो नः प्रचोदयात्॥

***

उस प्राणस्वरूप, दुःखनाशक, सुख स्वरूप,
श्रेष्ठ, तेजस्वी, पापनाशक, देवस्वरूप परमात्मा को
हम अन्तरात्मा में धारण करें। वह परमात्मा
हमारी बुद्धि को सन्मार्ग की ओर
प्रेरित करे।

*

— ऋग्वेद ३ ६२.१०

ACKNOWLEDGMENT

I express my deep sense of gratitude to my thesis supervisors Dr V K Jain and Dr S K Chaudhary for considerate yet rigorous and meticulous guidance I am deeply indebted to them for their inspiring guidance and devotion throughout the tenure of this work

I am very thankful to Dr Prashant Kumar for his guidance and valuable suggestions during designing of the experimental set-up **I am thankful to Extrude Hone Corporation, USA for supplying the media used in the process**

I am very grateful to the staff of Manufacturing science laboratory, Mr R M Jha, Mr Namdev murkhe and Mr H P Sharma for their consistent efforts in fabricating the experimental set -up

I am very thankful to Dr A P Verma and Mr R P Singh of H B T I, Kanpur for their help in surface roughness measurements

I am heartily greatful to Mr Neelesh Jain, Mr Manoj Singh, Ankulkar M S and all other friends who made my living at I I T , Kanpur memorable and enjoyable

I am thankful to my junior friends T Rajani kumar, Shivaramakrishna and K Ramesh for their help during fabrication of set-up

Lastly, I want to thank God for helping me to complete my work successfully and giving his blessings at every difficult moment

SUNIL JHA

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter- 1

INTRODUCTION

1.1 CONVENTIONAL FINISHING PROCESSES

Finishing costs in the metal working industries account for as much as 15% of the total manufacturing cost Finishing operations involved in the production of precision parts are the most labour intensive and least controllable ones

The dimensional and alignment accuracy, and quality of surface finish are taken care of by finishing processes Grinding, honing, lapping and superfinishing processes are the traditional methods of finishing The applications of these traditional abrasive finishing processes are limited to the production of shapes such as flat, cylindrical, etc With increasing cost of machining and introduction of high strength materials of complicated shapes, the need for accurate and reliable process arises A relatively new process called Abrasive Flow Machining (**AFM**) is being developed to provide accuracy, efficiency, and economy

1.2 ABRASIVE FLOW MACHINING (AFM)

Abrasive flow machining is an unconventional machining process used to deburr, polish, radius, remove recast layer and to induce compressive residual stresses by flowing a semi solid abrasive laden media (also called as media) over a selected area of the workpiece The AFM works on the principle that material removal is caused by extruding media back and forth through or across the passage formed by workpiece and tooling (Fig 1 1) Abrasion occurs only where the media flow is restricted, whereas other areas remain unaffected [10] A variety of finishing results can be achieved by altering the

process parameters Abrasive Flow Machining can reach even the most inaccessible areas, processing multiple holes, slots or edges in one operation

Advances in media formulation and tool design coupled with new capabilities in processing and automation have established the abrasive flow process as a way of satisfying tough manufacturing requirements economically and productively[10]

Abrasive Flow Machining offers precision, consistency and flexibility to a wide range of applications in aerospace, automotive and die finishing The process was initially developed to perform critical deburring of aircraft valve bodies and spools, as well as burr free internal edge An automatic AFM system can handle thousands of parts per day, greatly reducing labour costs by eliminating tedious hard work

With today's focus on total automation in flexible manufacturing system, the Abrasive Flow Machining process offers both automation and flexibility in final machining operations Further materials from soft aluminium to tough nickel alloys, ceramic and carbides can be successfully micromachined by this process Abrasive Flow Machining can be applied to an impressive range of finishing operations, providing uniform, repeatable and predictable results

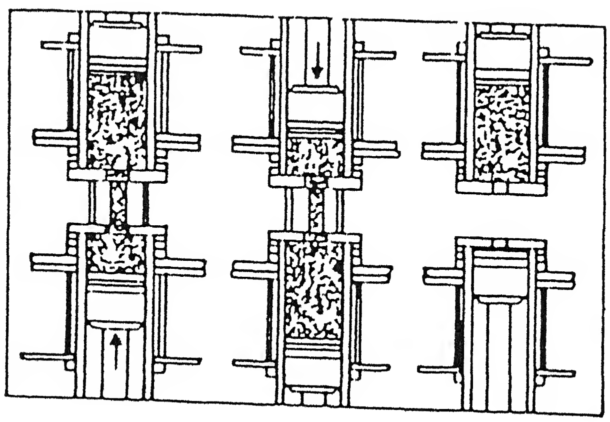


Fig 1 1 Abrasive flow machining process [9]

1.3 LITERATURE SURVEY

The Abrasive Flow Machining process has been developed and brought to production stage in U S A during the years of 1966 to 1968 In 1978, Abrasive Flow Machining was reported as an alternate for hand polishing of extrusion dies at the international aluminium extrusion technology seminar in Atlanta, Georgia

Przylenk [1] conducted some experiments on AFM and concluded that with small bore diameter more grains come in contact with the wall and material removal increases With increasing the number of cycles, first there is an increase in material removal due to higher initial coarseness of the workpiece surface, then it slightly decreases per cycle It was also found that the media should not be allowed to achieve temperature over 100 °C to keep the viscosity of the media within certain limits

Rhoades [2,3] studied the basic principle of AFM process and identified its process control parameters Tooling is used to direct the media to the desired areas in the workpiece The depth of cut primarily depends upon the size, relative hardness, sharpness of abrasive grains and extrusion pressure The number of cuts made by the slug (the media extruded through the workpiece, shown in Fig 1 1) during one cycle is a function of length of the media as it passes through the restriction, and size and concentration of abrasives in the media The applications of AFM in machining carbides are also reported The type of flow pattern to occur has been shown to be depend upon the machine setting, media formulation, workpiece and tooling configuration

Kohut Tom [4] presented some fundamentals of the process For any working pressure the amount of abrasion that occurs is directly related to the slug length of flow It has been shown that if the two passages of different areas are given the same volume flow, then the smaller passage abrades more than the large passage due to greater slug length of flow

Williams et al [5,6,7] carried out experiments on extrude hone model 77c and 7A The Experiments conducted by them are with different pressures and viscosities at 10 cycles It was observed that as pressure and viscoscity increases material removal increases while surface roughness value decreases

Perry [8] presented some applications of AFM in aerospace industries He found that the key feature differentiating AFM from most other finishing processes is the ability to control and select the intensity and location of abrading through fixture design and media selection The ability of AFM to work on selected edges, surfaces and internal or otherwise inaccessible sections confirms that many difficult finishing operations can be transferred to a mechanised process with its inherent consistency, repeatability, and cost effectiveness

Rhoades [9] observed that the type of flow pattern that occurs depends on the machine settings, the media formulation and workpiece and tooling configuration The machine controls the extrusion pressure ranging from 7 to 220 bars The volume of media flow depends on the displacement of piston of each media cylinder (i e stroke) and the total number of cycles required to complete the job Media flow rate is determined by media viscosity, extrusion pressure and passage dimensions which affects the amount of abrasion, the uniformity of stock removal and the edge radius size

N Studly [10] identified the wide range of feasible applications of the AFM process from critical aerospace and medical components to high production volume of parts The components are finished economically and productively with advances in media formulation and tool design coupled with new capabilities in processing and automation

Loveless et al [11] performed some experiments and found out that material removed from milled surface is more than that from the WEDM'd, turned and ground surface, keeping other parameters constant Material removal achieved from the ground surface is lowest among these AFM is able to remove almost all signs of the WEDM process, leaving a smooth polished surface

Dubey and Shan [12] studied the effect of the performance parameters on the process effectiveness They presented the results of an experimental investigation into some aspects of AFM process characteristics on work surface integrity The effect of number of AFM cycles, grit size, and abrasive concentration on metal removal and surface finish improvement by AFM was investigated by carrying out a set of experiments using full factorial design

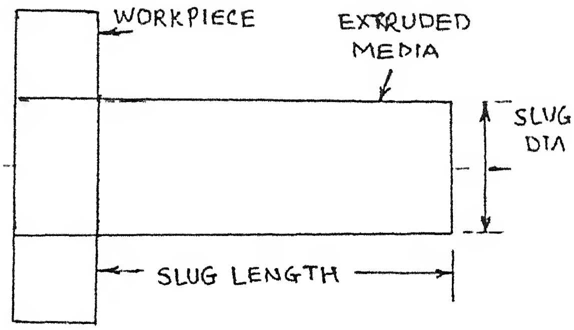


Fig 1 2 Slug

1.4 OBJECTIVES OF THE PRESENT WORK

The literature survey reveals that the earlier research work in the field of Abrasive Flow Machining was done on the commercially developed machines and only qualitative analysis was reported Following are the specific objectives of the present work -

1 To design and develop a hydraulically powered high pressure Abrasive Flow Machine set-up The work carried out under this heading can be classified as follows

(i) Design of hydraulic circuit

(ii) Selection of hydraulic components

(iii) Design and fabrication of frame & housing

(iv) Assembly of Abrasive Flow Machine set-up

2 To study the effect of varying pressure, number of cycles, and extrusion passage size on material removal and surface finish

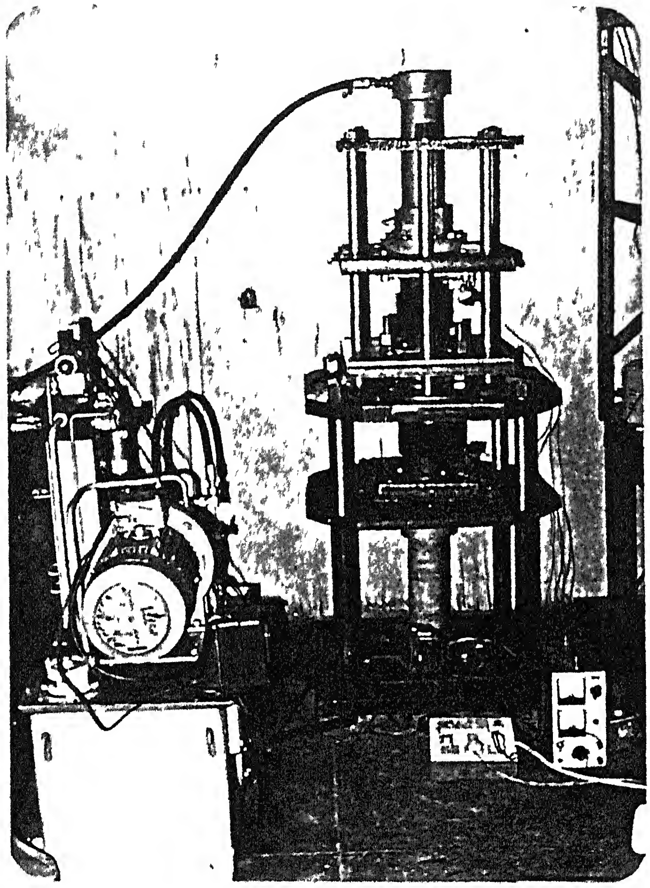


Fig 2 1 Photograph showing AFM set-up

Chapter -2

DESIGN OF EXPERIMENTAL SETUP

2.1 DESIGN OF ABRASIVE FLOW MACHINE COMPONENTS

The Abrasive Flow Machining set up has been designed keeping in view the fundamental mechanism of the process and the basic requirements In Abrasive Flow Machining, media is extruded through the passage formed in the workpiece by utilising two opposed piston media cylinders

The Abrasive Flow Machine set up shown in fig 2 1 consists of the following components

1 Media cylinders,

2 pistons,

3 Workpiece Fixture,

4 Hydraulic drive and controls,

5 Frame and housing

Media cylinders and pistons of LP genset, Kirloskar make have been chosen from the market In the following sections, critical dimensions have been calculated by designing them from the strength point of view

2.1.1. Media Cylinders :

The primary function of the media cylinder is to contain a sufficient quantity of the media at desired extrusion pressures While its secondary function is to guide the piston movement The thickness of the media cylinder which is determined so that it could withstand a maximum hydrostatic pressure of 100 bar The media cylinder is designed with a high wear resistant sliding surface For this a cast iron cylinder liner is

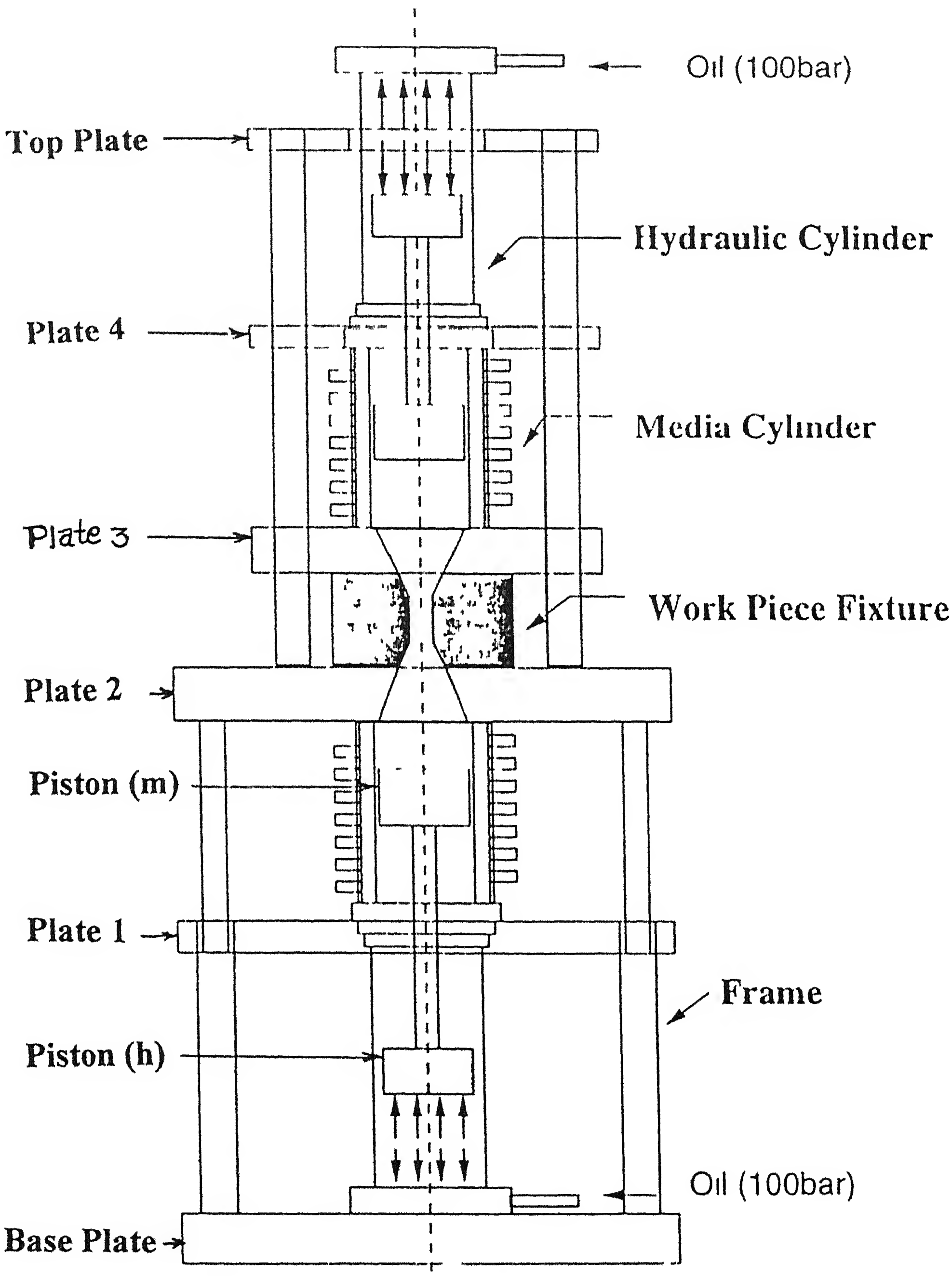


Fig 2 2 Abrasive Flow Machining Set-up

fitted inside the cylinder block

Analytically the following cylinder parameters are determined on the basis of Lame's thick pressure vessel theory[15]

Material Selected Grey cast iron (ISI Grade 35)

Ultimate Tensile Strength 320 MPa

Thickness of the media cylinder according to thin cylinder theory :

Wall Thickness $$t_b = \frac{p\, D_i}{2\, S_d} \quad \text{mm} \tag{2 1}$$

where, P = inside pressure, MPa

D_i = inner diameter, mm

S_d = design stress, MPa

inside pressure P = 10 MPa

inner diameter D_i = 87 5 mm

design stress $$S_d = \frac{S_{ut}}{8} = \frac{320}{8} = 40 \text{ MPa} \tag{2 2}$$

$$t_b = \frac{10 * 87\ 5}{2 * 40}$$

t_b = 10 9375 mm

$$\frac{t_b}{D_i} = 0\,125 > 0\,1$$ (Condition for thick cylinder)

By **Lame's Thick Cylinder Theory ,**

Wall Thickness $$t_b = \frac{D_i}{2}\left[\left(\sqrt{\frac{S_d + P}{S_d - P}}\right) - 1\right] \tag{2 3}$$

$$t_b = \frac{87\ 5}{2}\left[\left(\sqrt{\frac{40+10}{40-10}}\right) - 1\right]$$

t_b = 12 73 mm

The standard air cooled cylinder block with the following specifications is selected

SPECIFICATIONS :

Brand Name	KIRLOSKAR
Bore Size	87 5 mm
Stroke length	80 0 mm
Cylinder Block Thickness	6 0 mm
Cylinder Liner Thickness	6 5 mm
Total Wall Thickness	12 5 mm

The extra strength to the cylinder block is provided by the 14 fins each of 3 mm thickness on the outer periphery Fig 2 3 shows the media cylinder

2.1.2. Pistons :

The media piston (piston(m) in Fig 2 2) acts to transmit the extrusion force applied by the piston rod of hydraulic cylinder to the abrasive media It is used to extrude the media from the media cylinder through the workpiece into the receiving cylinder (media cylinder on the other side) The main extruding surface is formed by the piston head which accommodates two cast iron rings (not shown in Fig 2 1) to provide sealing and reduce frictional resistance

The functional requirements of the pistons are

- Compressive strength
- Wear resistance

Force acting on the piston $F =$ Pressure X Cross-sectional area of piston

Cross-sectional area of piston $A = 5026\ 55\ mm^2$

Force $F = 10 \times 5026\ 55$ N = 50 265 kN

Pistons made up of Aluminium alloys, supplied along with the Kirloskar cylinder blocks can fulfill our functional requirements

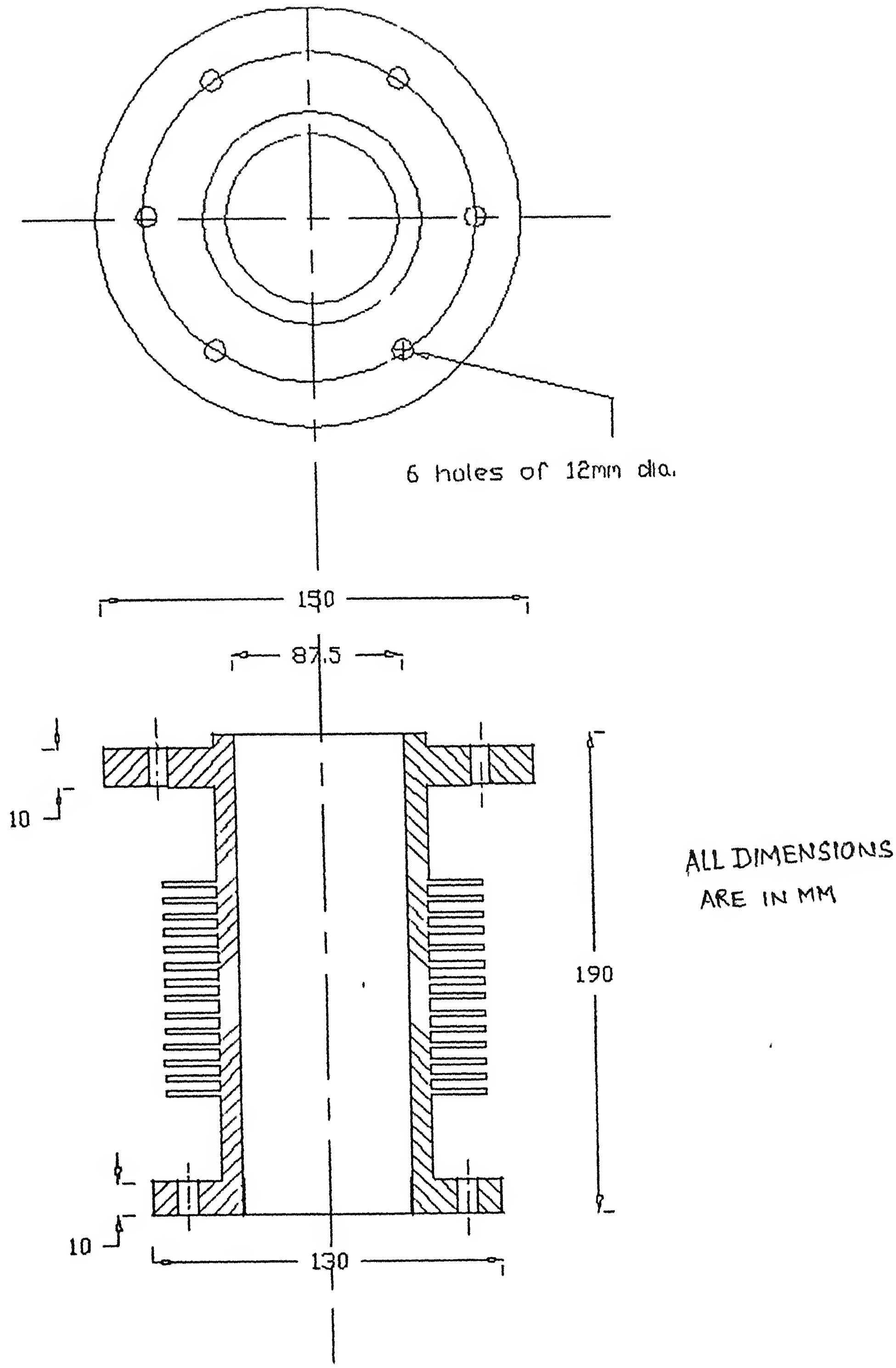


Fig 2 3 Media cylinder

2.1.3 Workpiece Fixture

Workpiece fixture in AFM depends on the workpiece configuration Keeping in view the fixture design considerations fixturing arrangement as shown in Fig 2 4 is fabricated to fulfill the requirements The fixture is fabricated for finishing internal holes and cavities The workpiece fixture consists of two square plates with cylindrical projection having taper passage for media flow, a cylindrical disc for holding workpiece holder and workpiece U- shaped workpieces with threaded hole are prepared to avoid the detachment of the workpiece from the holder at high pressure After placing the workpiece in the slot made for it, it is tightened up by a screw The workpiece holder is then placed inside the small circular disc The circular disc is placed in the middle cylindrical disc and then whole assembly is tightened between two square plates by bolts The fixture is then placed between the two media cylinders

2.1.4. Hydraulic Drive And Controls .

A hydraulic circuit is an arrangement of components interconnected to provide a desired form of fluid power In the AFM, the operations are powered by the hydraulic drive The hydraulic system refers to the complete assembly of component parts that transmit and control the fluid power Fig 2 5 shows the block diagram of a hydraulic system

The design of hydraulic system for AFM comprises of

- Component selection factors
- Calculation of specification data
- Operating information
- Graphical diagramming

Fig 2 6 shows the hydraulic circuit for AFM The system has following components

1 Reservoir (R)

2 Strainer (S)

3 Variable delivery pump (VDP)

4 Flexible coupling

5 Electric motor (M)

6 Connectors

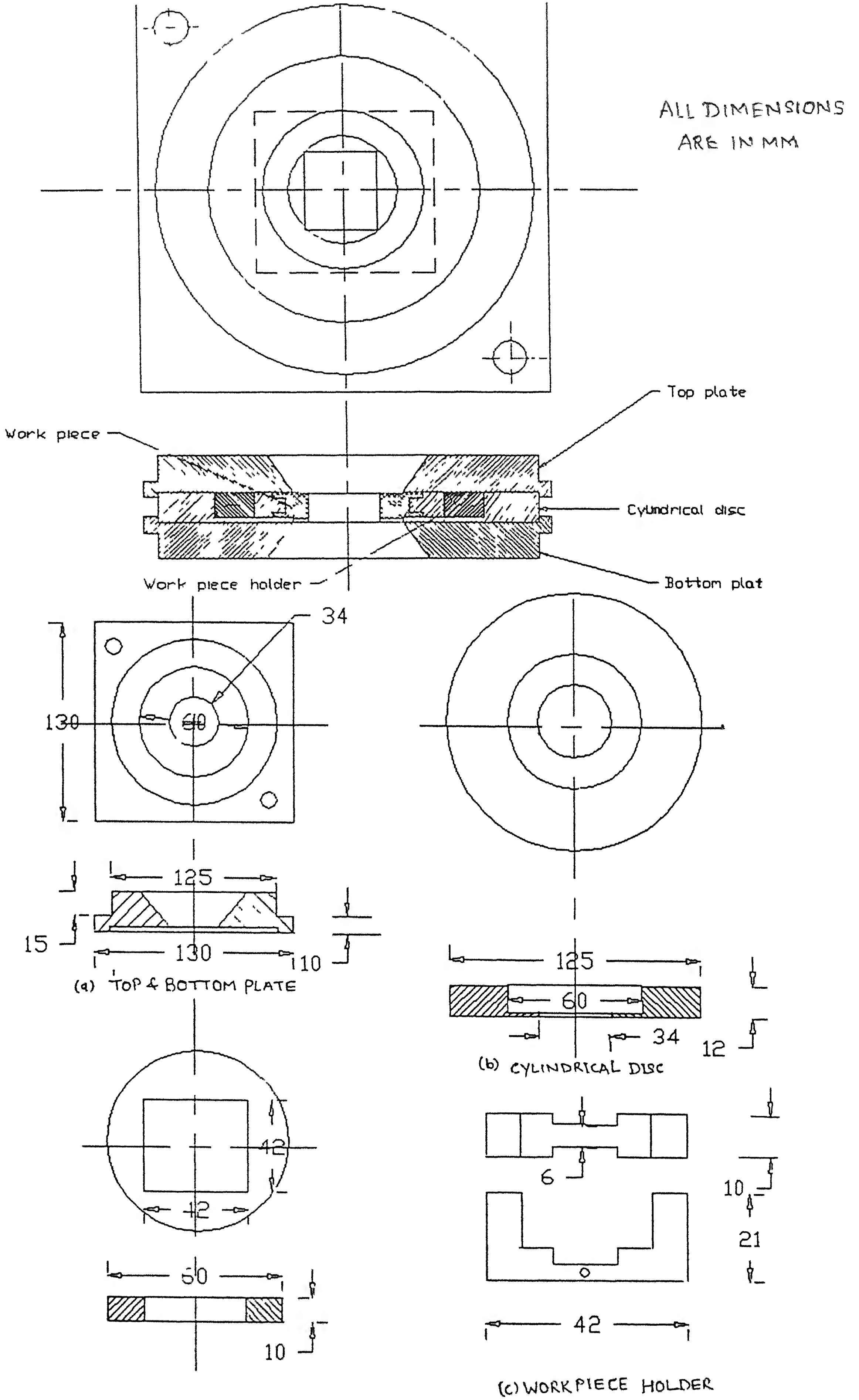


Fig 2 4 Work piece fixture

7 Relief valve (RV)

8 Check valve (CV)

9 3-Position 4-way Direction control valve (DCV)

10 Single acting cushioned cylinders (HC1 & HC2)

The component selection procedure of Hydraulic circuit for AFM is explained below

1 SPECIFICATIONS FOR THE JOB

- Pressure requirement

  Maximum Pressure = 10 MPa

- Max length of stroke = 200 mm

2 SIZE OF HYDRAULIC CYLINDERS

To meet the requirement of AFM the cylinder bore size is selected according to the maximum operating pressure Referring to the standard bore and rod sizes for cylinders, selection is made on the basis of reasoning that a smaller diameter cylinder operate at a high pressure, but requires a smaller pump to give the required cylinder speed and vice versa

The specifications of hydraulic cylinder selected are

i) Bore size = 80 mm

ii) Stroke = 200 mm

iii) Max Operating Pressure = 10 MPa

3 PUMP CAPACITY

The pump is selected to provide the maximum piston speed required by the hydraulic oil in the circuit

$$\text{Volume flow rate, } Q = \frac{\text{Cross-sectional area of cyl X Length of stroke}}{\text{Time for one stroke}}$$

(2 4)

Cross-sectional area of hydraulic cylinder = 5026 55 mm^2 (Dia of cylinder = 80 0 mm)

Length of media cylinder stroke = 80 0 mm

Max no of cycles per min = 15 cycles (or 30 stroke)

Time for one stroke = 2 0 secs

$$Q = \frac{502655 * 80}{20} = 12\ 06 \text{ litres/min}$$

Maximum pressure = 10 Mpa

Standard variable delivery vane pump with Max flow rate of 10 0 lpm is selected

4 RELIEF VALVE

A simple relief valve fitted with a spring having a range setting between 0 and 10 Mpa is selected The relief valve is adjusted manually to any desired pressure

5 DIRECTIONAL CONTROL VALVE

The type of valve actuation depends on its application The primary function of a 4-way direction control valve is to alternately pressurize and exhaust two working ports Two position 4-way valves are used to reciprocate and hold an actuating cylinder in one position Direction control valve with a center position allow the machine to stop without shutting down the entire system Solenoid operated direction control valve is selected which is powered through 220 V ac and activates through the control circuit

WORKING OF HYDRAULIC CIRCUIT :

The pump VDP (Fig 2 6) withdraws oil from the inlet line C and delivers it to the outlet line D at a volumetrically uniform rate for any particular setting The direction of flow is reversed by means of valve DCV so that line P is connected to either of the cylinder

To ensure that the maximum pressure is limited, a shunt line G is provided, communicating with reservoir R by way of a relief valve RV3 It is apparent that, with this arrangement, the rate of advance of the piston P1 is determined by the rate of withdrawal of oil from the hydraulic cylinder HC2, and as oil is passed through the pump VDP at a volumetrically uniform rate, the piston would advance at an uniform speed provided that the oil is incompressible

During forward stroke of the cycle oil enters from the port P of the direction control valve (DCV) and flows into the line A connected to parallely arranged check valve and relief valve for pressure control in the cylinders Initially RV1 and RV2 are adjusted manually for a particular pressure In forward stroke the oil passes from CV1 into HC1 till the pressure in the hydraulic cylinder HC2 reaches the adjusted pressure As the pressure exceeds the adjusted value, the RV2 gets opened and oil comes out from HC2, making piston P1 traversing in downward direction After completing forward stroke the direction of DCV is reversed by relays and oil flow is reversed to complete one cycle

2.1.5 Frame And Housing

Frame and housing are necessary to accommodate different components of the abrasive flow machine together for its operation as a single unit Frame is designed to provide safe operation and to withstand the working stresses

Force analysis :

For designing various members of the frame, the force analysis is done by making free body diagram of the system (Fig 2 7)

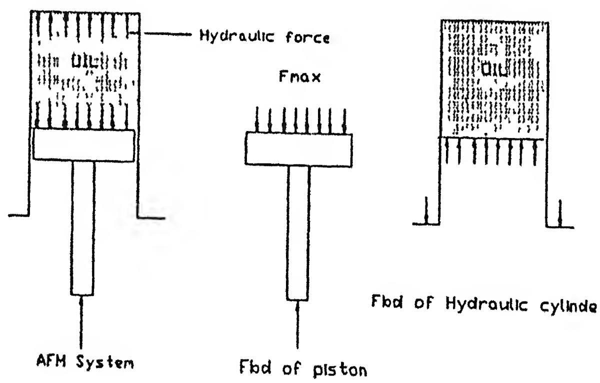


Fig 2 7 Free body diagram of AFM system

Force of the system goes to the flange of the cylinder and then to the frame As all the forces are axial, the frame must be rigid enough to counter axial forces

Maximum hydraulic pressure = 10 Mpa

Cross-section Area of the hydraulic cylinder = 5026 5 mm^2

The maximum force on the flange of the hydraulic cylinder,

F_{max} = Max pressure x Cross- sectional area of hydraulic cylinder = 51 kN (2 5)

Frame is fabricated using mild steel plates and circular bars The frame consists of

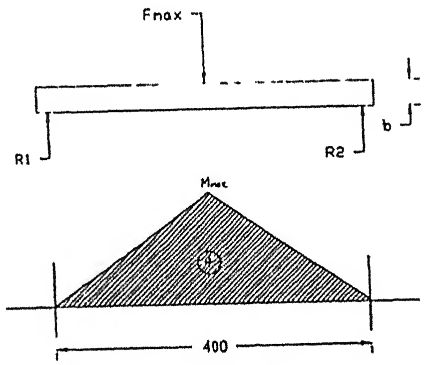
1 Base plate
2 Supporting plates
3 Guiding plates
4 Top plate
5 Supporting bars

CALCULATION OF PLATE THICKNESS

The maximum force coming on the flange of the hydraulic cylinder is transmitted to the supporting plates

$P_{max} = 10$ MPa $\qquad\qquad F_{max} = 51$ kN

Considering the plate as a simply supported beam and loads to be concentrated one



Bending moment diagram

Fig 2 8 Free body diagram of plate

$R_1 + R_2 = F_{max}$

$R_1 = R_2 = F_{max}/2$ (by symmetry)

Maximum bending moment occurs at the center and is given by

$$M_{max} = \frac{FL}{4} \qquad (2\ 6)$$

where,

F = bending force, N

L = length of the plate, m

$$M_{max} = \frac{51 X 10^3 X 0\ 40}{4} = 5100 N - m$$

Bending stress in simply supported beam is given by,

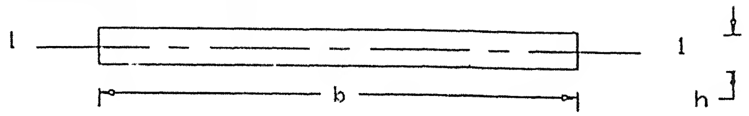
$$\sigma_b = \frac{M_{\max}}{Z} \qquad (2\ 7)$$

where,

$M_{\max}$ = maximum bending moment

Z = section modulus

cross-section of beam



section modulus about 1-1 is

$$Z = \frac{bh^2}{6} \qquad (2\ 8)$$

Taking material of plate as carbon steel C-35

Yield stress $\sigma_{yp} = 300\,MPa$

Plates are having many holes, therefore factor of safety is taken as N = 5 keeping in view the stress concentration

$$\text{Allowable stress } \sigma_{all} = \frac{\sigma_{yp}}{N} = \frac{300}{5} = 60\,MPa \qquad (2\ 9)$$

For safer design, the bending stresses in the plates should be less than the allowable stress Therefore the section modulus of the plate should be greater than

$$Z = \frac{M_{\max}}{\sigma_{all}} = \frac{5100}{60X10^6} = 8\,5X10^{-5}\,\mathrm{m}^3$$

From eqn 2 6 $\qquad h^2 = \frac{6Z}{b} = \frac{6X8\,5X10^{-5}}{0\,40} = 1\,275X10^{-3}m^2$

Here, value of 'b' is assumed to be 400 mm

The thickness of the plate should be greater than $h = 0\,0357m = 35\,7mm$

Plates of 40 mm thickness are selected from the available thickness in the market

CHECK FOR DEFLECTION

Maximum deflection in case of a simply supported beam is given by,

$$y_{max} = \frac{PL^3}{48EI} \qquad (2\ 10)$$

where,

P = force, N

L = length of beam, m

E = modulus of elasticity, N/m^2

I = moment of inertia, m^4

Moment of Inertia of a rectangular cross-section is given by,

$$I = \frac{bh^3}{12} \qquad (2\ 11)$$

$$I = \frac{0\ 40X(0\ 04)^3}{12} = 2\ 13X10^{-6}m^4$$

$E = 2\ 1X10^{11}\ N/m^2$ (For carbon steel)

From eqn 2 10, the deflection in the plate is,

$$y_{max} = \frac{51X10^3X(0\ 40)^3}{48X2\ 1X10^{11}X2\ 13X10^{-6}} = 1\ 52X10^{-4}m = 0\ 152mm$$

This deflection is insignificant

SUPPORTING BARS

Four supporting bars are used to support the plates Diameter of the bars are calculated from the formula

Cross-Sectional Area X Allowable Stress = Max Tensile force

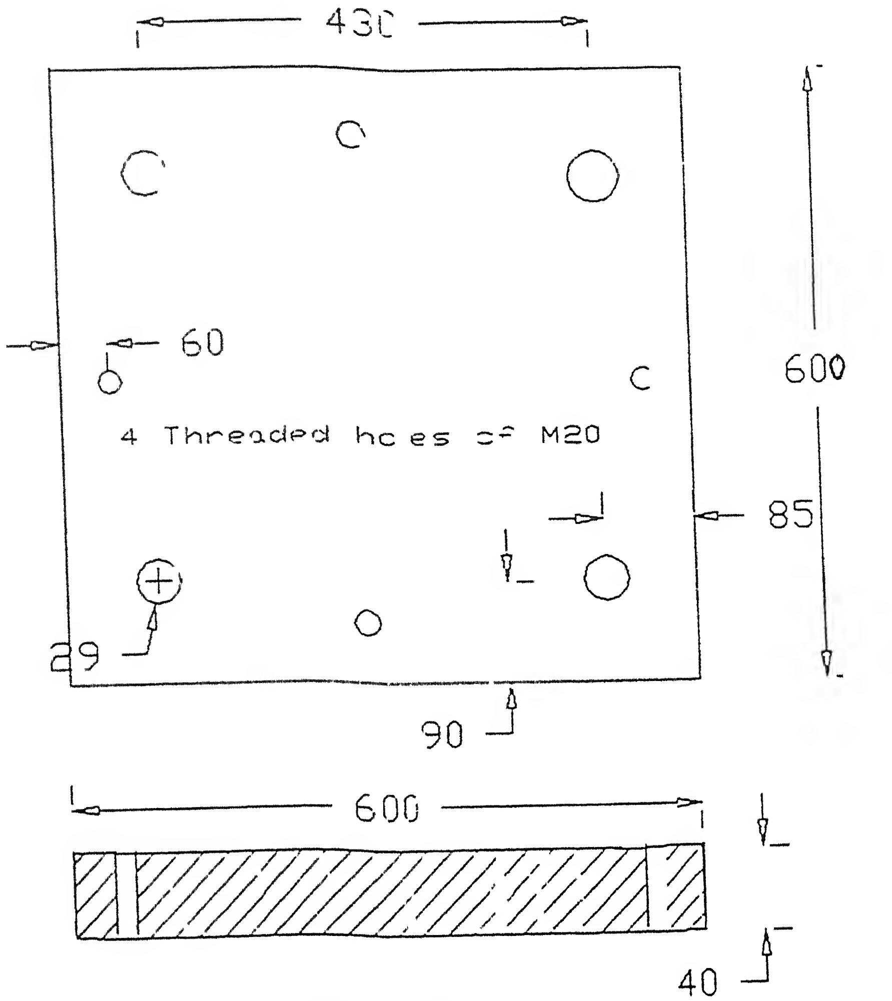
Allowable Stress for C-25 carbon steel (Taking N = 4) $\sigma_{all} = 70MPa$

F_{max} = 51 kN (from eqn 2 5)

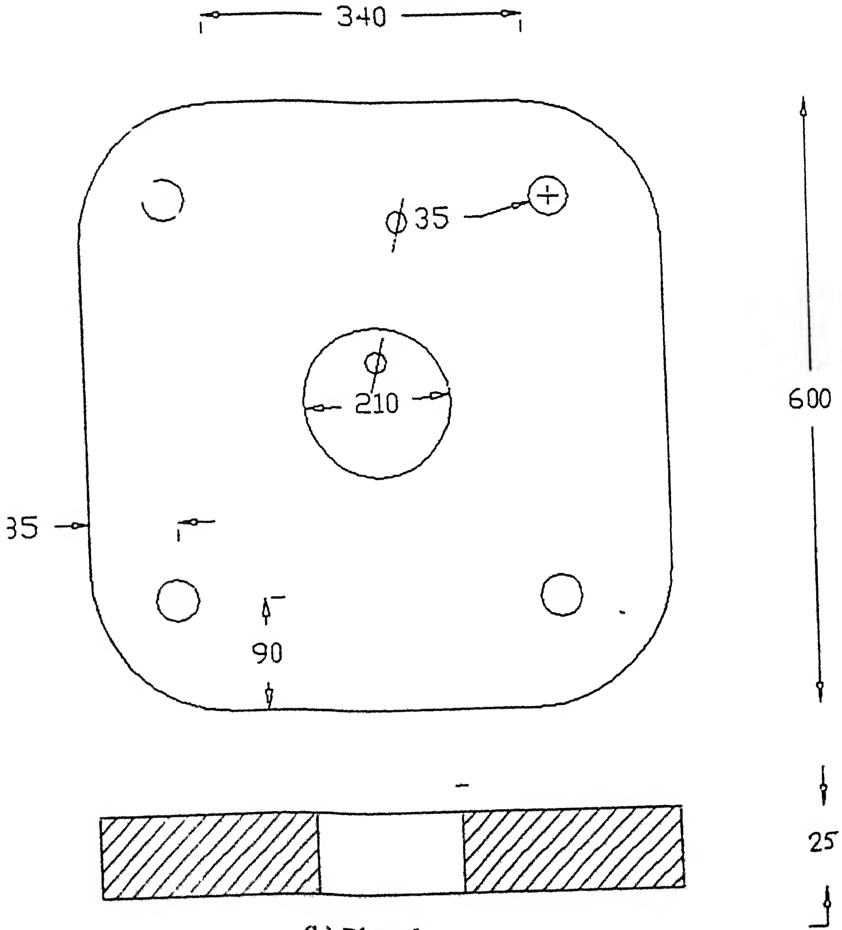
Cross-sectional Area $A = \frac{51X10^3}{70X10^6} = 7\ 286X10^{-4}m^2$

Diameter of circular bars $d^2 > \frac{7\ 286X10^{-4}}{\pi}$ $\qquad d > 0\ 0153m$

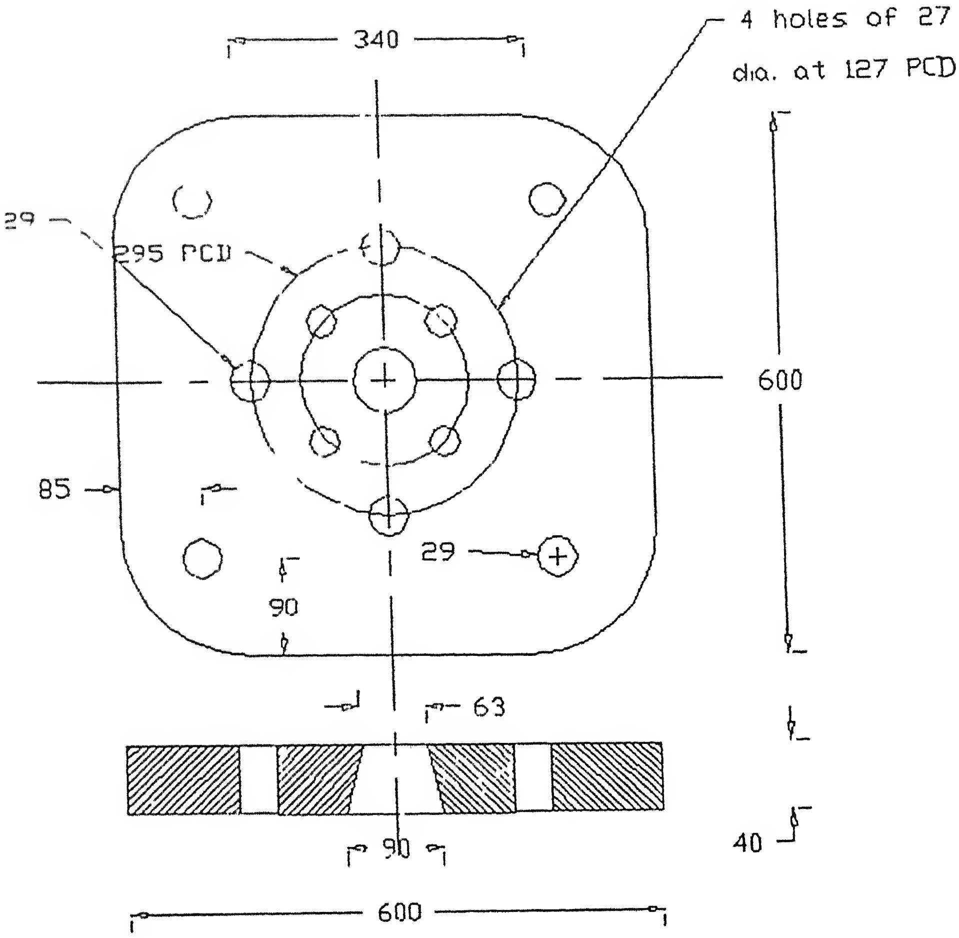
The diameter of the bar on which critical tensile force is coming is taken as 20 mm



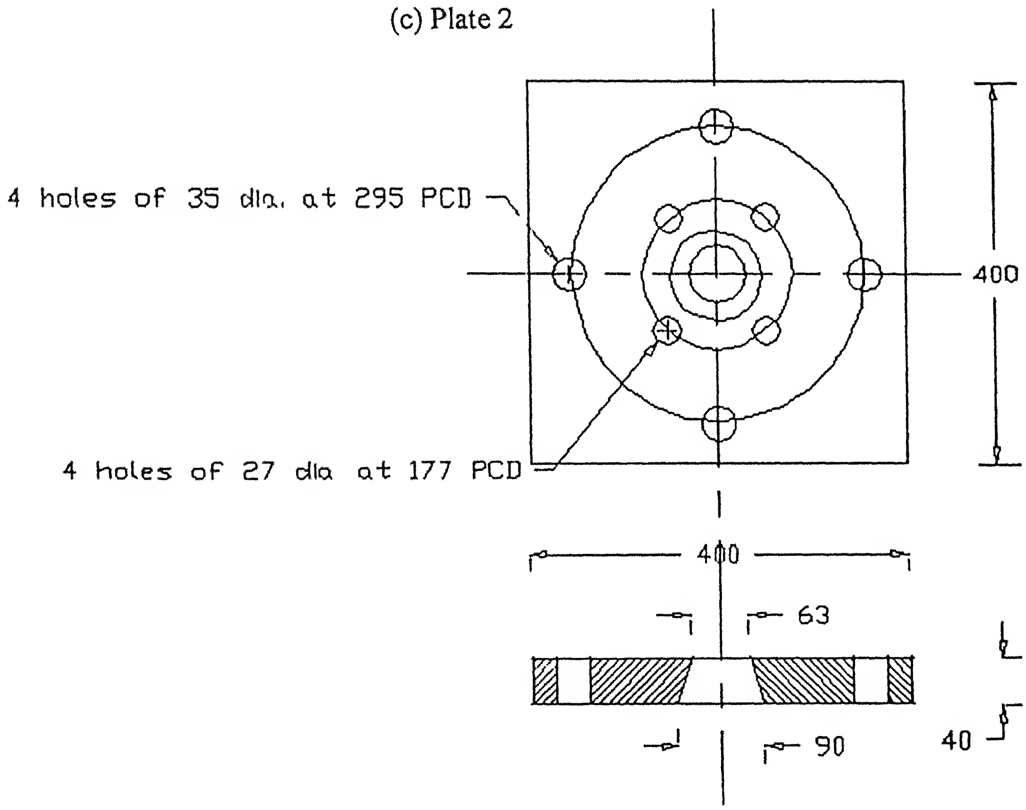
(a) Base Plate



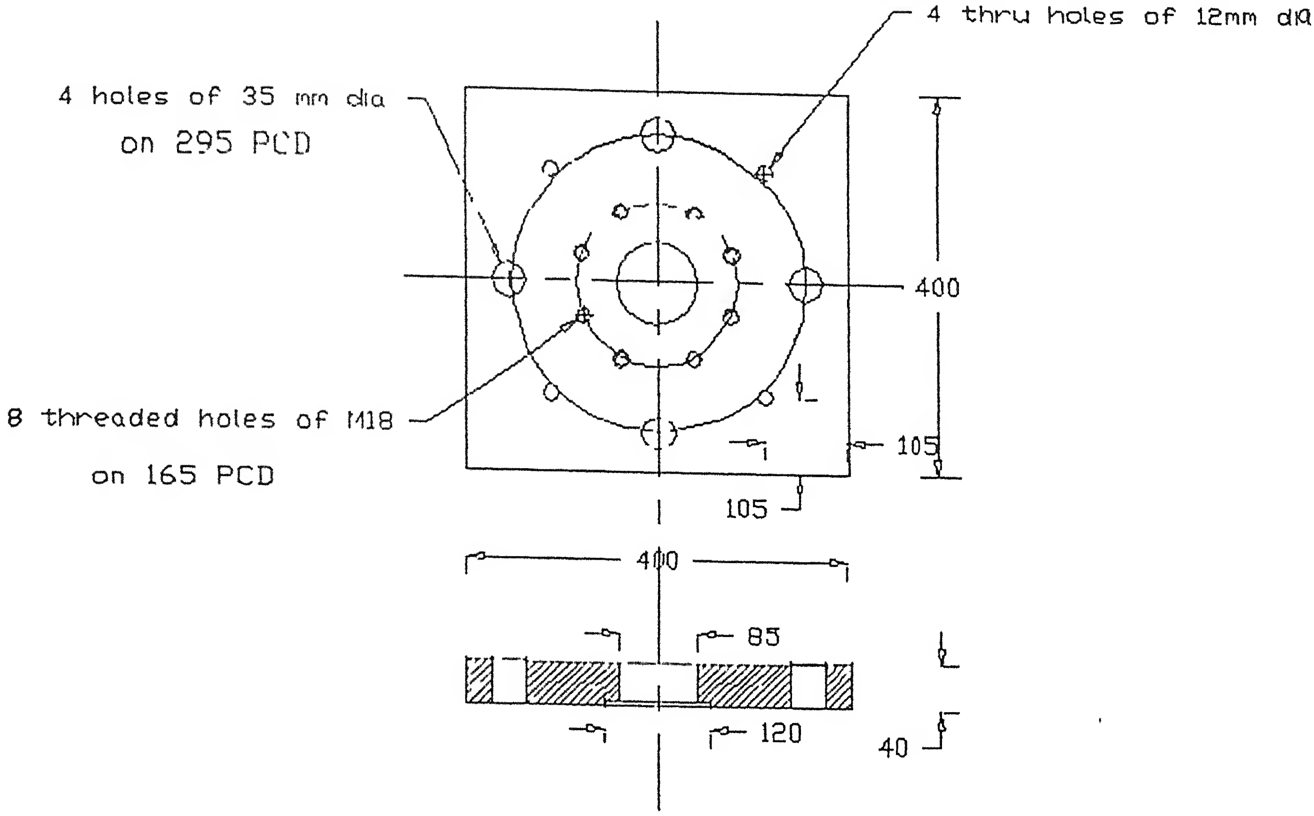
(b) Plate 1



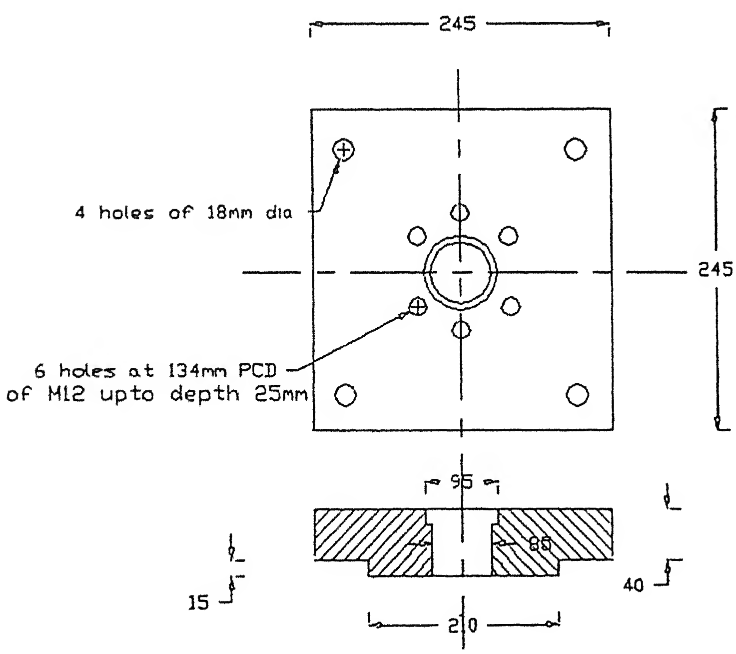
(c) Plate 2



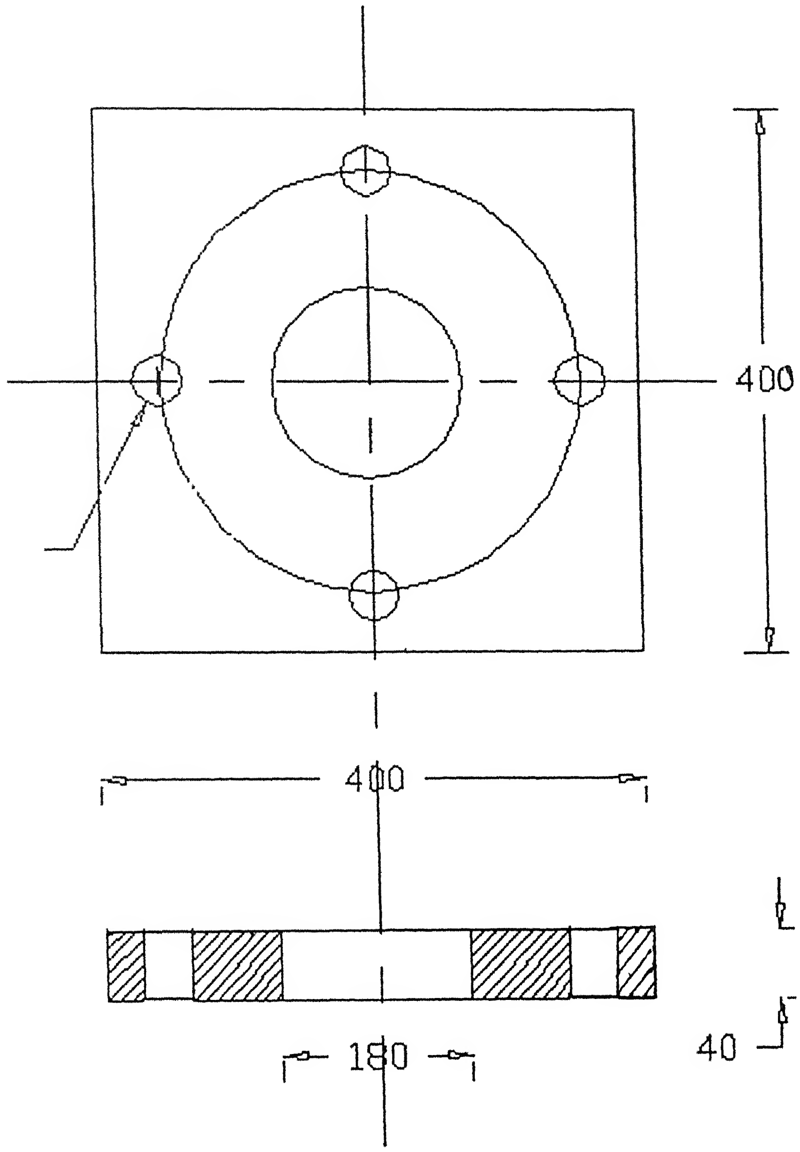
(d) Plate 3



(e) Plate 4



(f)Plate 5



(g) Top Plate

ALL DIMENSIONS ARE IN MM.

Fig 2 9 Part drawings of frame

2.1.6 Electrical Control Circuit

In the AFM set-up, the solenoid operated direction control valve is used The two solenoids are mounted at the two ends of the valve To energize the solenoid, 220 V a c is required The electrical control circuit is required to keep the solenoid in energized position till the piston traverses the stroke length and presses the limit switch For this a logic circuit is formed using two 6V d c DPDT relays Fig 2 10shows the the circuit diagram Two neon lamp indicators are also connected to the relays to indicate the direction of piston movement Two push buttons are mounted on the panel to manually control the piston movement

2.2 WORKING OF THE AFM SET-UP

Before starting the experimentation, any one of the media cylinder is filled completely with the media Then the workpiece fixture is placed between the plates 3 and 4 and the two plates are tightened by nuts and bolts To start the hydraulic unit , press the green button of the starter mounted on the hydraulic power pack The desired extrusion pressure is adjusted by the relief valve RV1 There are two more pressure relief valves RV2 and RV3 for controlling the back pressure The back pressure is necessary in the case when the media is required to be compressed during machining. This will probably help in increasing the depth of the cut by making the abrasives to penetrate to a greater depth

To activate the control circuit press any limit switch , which sends signal to the relay This will lead the piston of direction control valve to be shifted in one position resulting the oil to enter into the hydraulic cylinder The flow rate of oil is adjusted through the arrangement provided in the pump Suppose the oil enters initially into the hydraulic cylinder HC1 The media in the media cylinder MC1 then starts extruding through the workpiece into the media cylinder MC2 which is acting as a receiving cylinder When the piston of MC1 traverses a length equal to the stroke length then the limit switch fixed at the end of MC2 gets pressed and causes the direction of flow of oil reversed through direction control valve Now the media cylinder MC2 is acting as a extruding cylinder and MC1 as the receiving one for next half cycle In this way, one cycle is completed to count the no of cycles and measure the cycle time a plotter is attached to the set - up When the desired no of cycles are completed, switch off the hydraulic unit from the starter by pressing red button

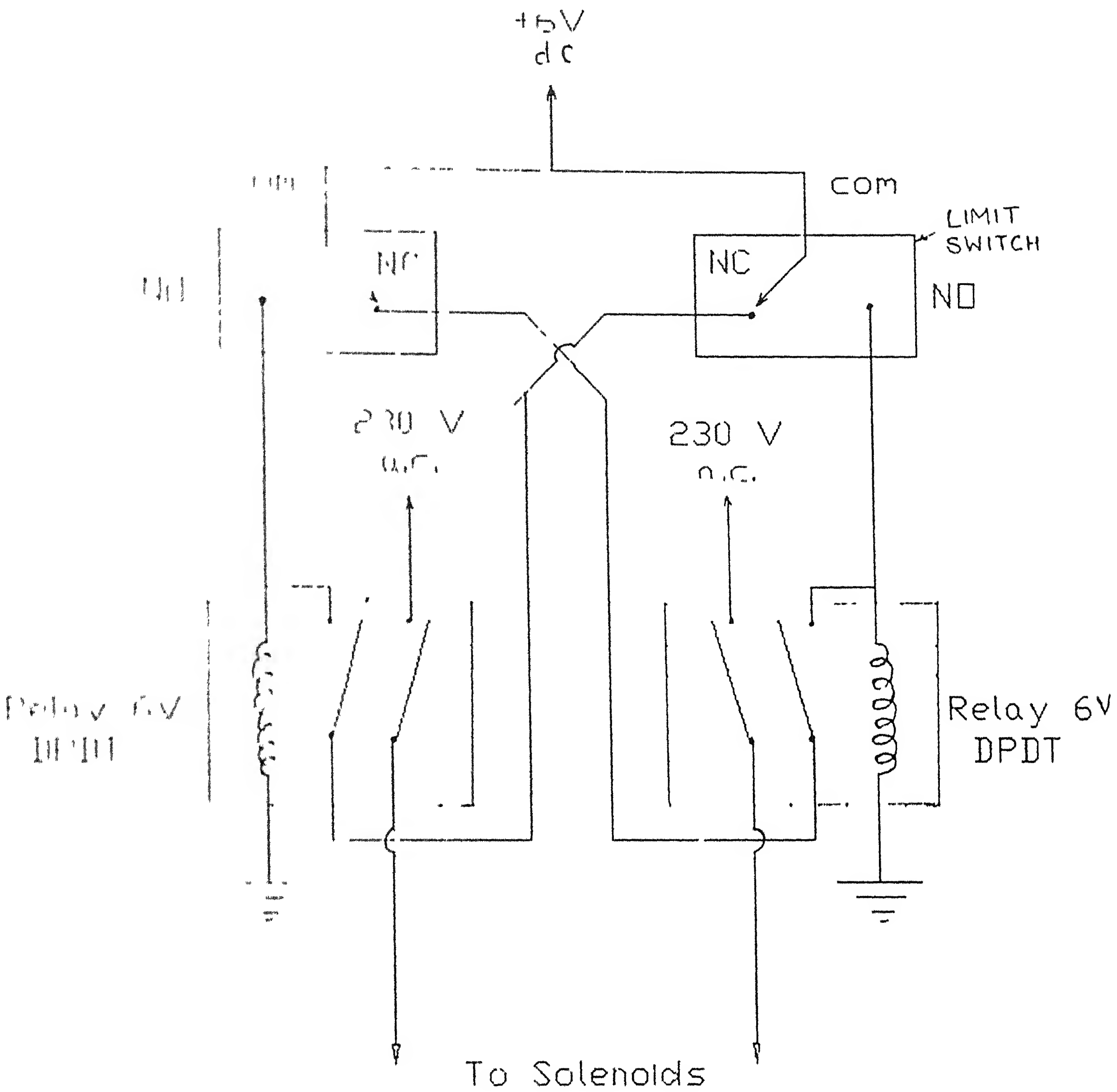


Fig 2 10 · Electrical control circuit

Chapter -3

PLAN OF EXPERIMENTS

3.1 STATISTICAL APPROACH

Experiments are planned in such a way that we can get useful inferences by performing minimum number of experiments This can be done by using statistical techniques. If the yield or response 'Y' is a function of the levels of quantitative variables then we may write[13].

$$y_u = \phi(x_{1u}, x_{2u}, \ldots, x_{ku}) + e_u \qquad (3\ 1)$$

where, u = 1,2, ... N represent the N observations in the factorial experiment,

and x_{iu} represents the level of the ith factor in the uth observation

The function ϕ is called the *Response Surface* The residual e_u measures the experimental error of the uth observation A knowledge of the function ϕ gives a complete summary of the results of the experiment and also enables us to predict the response for the values of the x_{iu} that were not tested in the experiment

When the mathematical form of ϕ is not known, this function can sometimes be approximated satisfactorily, within the experimental region by a polynomial in the variables x_{iu} Some experimental designs and methods of analysis are developed for fitting polynomial of the first and second degree

3.1.1 The Quadratic Response Surface

The general form of a quadratic (second degree) polynomial is illustrated by the

equation $$y_u = b_0 + \sum_{i=1}^{k} b_i x_{iu} + \sum_{i=1}^{k} b_{ii} x_{iu}^2 + \sum_{i<j}^{k} b_{ij} x_{iu} x_{ju} \qquad (3\ 2)$$

Where, k= No of variables

The surface contains linear terms in (x_m), squared terms (x_m^2) and the cross product terms (x_i x_j)

3.1.2 Central Composite Rotatable Design

The design for three x - variables is shown in table 3 1 The columns headed and X_1 X_2 and X_3 which specify the actual combinations to be used, constitute the plan of experiment

Table 3.1 : Central composite rotatable design for k = 3 [13]

X	X_1	X_2	X_3	X_1^2	X_2^2	X_3^2	X_1X_2	X_1X_3	X_2X_3	Y
1	-1	-1	-1	1	1	1	1	1	1	
1	1	-1	-1	1	1	1	-1	-1	1	
1	-1	1	-1	1	1	1	-1	1	-1	
1	1	1	-1	1	1	1	1	-1	-1	
1	-1	-1	1	1	1	1	1	-1	-1	
1	1	-1	1	1	1	1	-1	1	-1	
1	-1	1	1	1	1	1	-1	-1	1	
1	1	1	1	1	1	1	1	1	1	
1	1 682	0	0	2 828	0	0	0	0	0	
1	1 682	0	0	2 828	0	0	0	0	0	
1	0	-1 682	0	0	2 828	0	0	0	0	
1	0	1 682	0	0	2 828	0	0	0	0	
1	0	0	-1 682	0	0	2 828	0	0	0	
1	0	0	1 682	0	0	2 828	0	0	0	
1	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	
1	0	0	0	0	0	0	0	0	0	

Computational steps are as follows

1. Complete the columns headed $x_i, x_i^2, x_1^2, x_2^2, x_3^2, x_1x_2, x_1x_3, x_2x_3$ as shown The two way table with 10 columns and 20 rows comprises the X-matrix of the x - variables The corresponding values of the response Y are placed on the right

2. Form the sum of products of each column in the matrix X with the column of Y where these sum of products are denoted by (0y), (1y), (2y) and so on

3. From the values of (0y), (1y), etc the regression coefficients are computed directly by the equations given below

$$\left.\begin{aligned} b_0 &= 0\ 166338(0y) - 0\ 056791\Sigma(iiy) \\ b_i &= 0\ 073224(iy) \\ b_{ii} &= 0\ 062500(iiy) + 0\ 006889\Sigma(iiy) - 0\ 056791(0y) \\ b_{ij} &= 0\ 125000(ijy) \end{aligned}\right\} \qquad (3\ 3)$$

4. In the analysis of variance, the sum of squares of the y's are partitioned into the contribution due to a first order (linear) equation and due to the second order (quadratic) terms

3.2 PLAN OF EXPERIMENTS

In the present experiments, the effect of three quantitative factors viz Pressure, Number of cycles and Percentage passage area reduction are studied on material removal and percent change in surface finish

A preliminary step is to set up the relations between the coded x-scales and the original scales in which the levels are recorded

In design scale the lowest and the highest values of x are -1 682 and +1 682 So we take,

x = -1 682 when P = 20 bar , N = 3 cycles , A = 0 %

x = +1 682 when P = 60 bar , N = 25 cycles , A = 80 %

Then,

$$x = a + b * (variable) \qquad (3\ 4)$$

'a' and 'b' are chosen to satisfy the desired conditions at the end of the scale

(i) *Pressure (P)*

$$x = a + b * (P)$$

when x = -1 682 , P = 20 bar

x = +1 682, P = 60 bar

On solving we get,

$$a = -3 364$$

$$b = 0 0841$$

The relation for pressure is $x = -3\,364 + 0\,0841P$ (3 5)

(ii) *Number of cycles (N)*

$$x = a + b * (N)$$

when x = -1 682 , N = 3 cycles

x = +1 682, N = 25 cycles

On solving we get,

$$a = -2\,1407$$

$$b = 0\,1529$$

The relation for number of cycles is $x = -2\,1407 + 0\,1529N$ (3 6)

(iii) *Percentage passage area reduction(A)*

$$x = a + b * (A)$$

when x = -1 682 , A = 0 %

x = +1 682, A = 80 %

On solving we get,

$$a = -1\,682$$

$$b = 0\,0420$$

The relation for percentage passage area reduction is $x = -1\,682 + 0\,0420A$ (3 7)

From these equations the pressure, number of cycles, and % passage area reduction corresponding to level x=-1, 0, +1 are determined The complete conversion is tabulated in table 3 2

Table 3.2: Conversion table

X	P	N	A
-1 682	20	3	0 %
-1	28	7	16 24 %
0	40	14	40 %
1	52	21	63 86 %
1 682	60	25	80 %

With the above conversions the experiments are performed according to the plan given below in table 3 3

Table 3.3 : Plan of Experiments

EXPT NO	X_1(P)	X_2 (N)	X_3 (A)
1	28 bar	7 cycles	16 24 %
2	28 bar	20 cycles	63 86 %
3	52 bar	20 cycles	63 86%
4	28 bar	7 cycles	63 86%
5	40 bar	3 cycles	40%
6	52 bar	20 cycles	16 24%
7	40 bar	14 cycles	40%
8	40 bar	14 cycles	40%
9	52 bar	7 cycles	63 86%
10	20 bar	14 cycles	40%
11	28 bar	20 cycles	16 24%
12	40 bar	14 cycles	80%
13	40 bar	25 cycles	40%
14	40 bar	14 cycles	40%
15	40 bar	14 cycles	40%

[illegible]	30 bar	14 cycles	40%
1	60 bar	14 cycles	40%
18	40 bar	14 cycles	0%
[illegible]	40 bar	14 cycles	40%
[illegible]	52 bar	7 cycles	16 24%

3.3 SURFACE FINISH MEASUREMENT

To study the change in surface texture due to various process parameters, The surface roughness measurements are essential Fo this purpose the instrument used is "TAYLOR HOBSON SURTRONIC 3P" It gives on its digital scale the Ra value, Rymax and Rtm

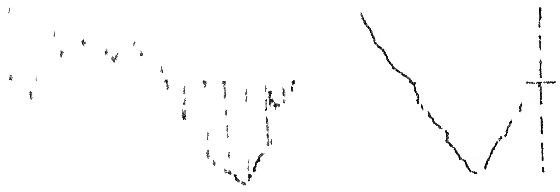
Before using the instrument, it is to be checked against the standard specimen provided by the manufacturer The procedure for surface roughness measurement is as follows

1 The pick-up of the traversing unit of the instrument is placed gently on the workpiece, so that the stylus of the instrument will touch the surface to be measured
2 Adjust the rotary switch first to Ra value and then press the start button
3 Surtronic 3P after traversing a sample length will display the Ra value directly
4 Now rotate the rotary switch to Rymax, it will directly give Rymax
5 For measuring Rtm the switch is rotate to Rtm and then press the start button again

This wil give Rtm value after traversing the sample length

The surface roughness is assessed by measuring Ra, Rymax and Rtm values before and after machining

Ra value The Ra height of the roughness irregularities on a surface is defined as the average value of the departures from its centre line throughout a prescribed sampling length (Fig 3 1) The Ra value of the surface is then the average height of the profile above and below the centre line



$$R_a = \frac{h_1 + h_2 + \dots h_n}{n}$$

Fig 3 1 Ra value

R_t This is the maximum peak to valley height of the profile in the assesment length

R_{ti} R_{ti} is maximum peak to valley height of the profile in one sampling length

R_{tmax} R_{tmax} is the largest R_{ti} value within the assesment length

R_{tm} R_{tm} is the mean of all the R_{ti} values obtained within the assesment length

$$R_{tm} = \frac{R_{t1} + R_{t2} + \dots + R_{tn}}{n}$$

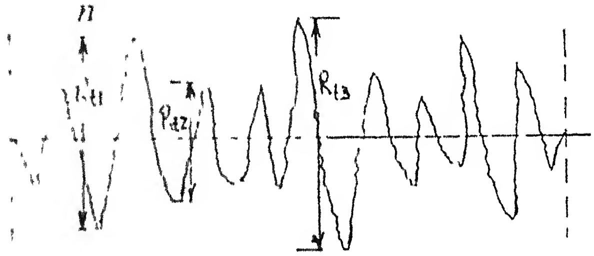


Fig 3 2 Surface irregularities showing R_{ti} values

3.4 MATERIAL REMOVAL

For material removal measurement, the electronic weight balance "AFCOSET FX-400" is used This weight balance is digital and can measure upto 0 0001 gm First of all tare button is pressed to set initially zero display on the screen Now place the workpiece on the platform of the weight balance and wait for few seconds so that the reading become stable This will give the weight of the sample By measuring the weight of the samples before and after machining , the material removed is calculated by taking their difference

3.5 TABULATION OF EXPERIMENTAL DATA

The experimental data are tabulated below

Table 3.4 : Material Removal Measurement (Brass)

EX PT NO	P bars	N cycles	A %	WEIGHT BEFORE MACHINING (gm.)				WEIGHT AFTER MACHINING (gm.)				MR (mg.)
				1	2	3	avg	1	2	3	avg.	
1	28	7	16.24	5 098	5 096	5 097	*5 097*	5 088	5 087	5 088	*5 0877*	9 30
2	28	21	63 86	6 592	6 592	6 593	*6 5923*	6 566	6 566	6 567	*6 5663*	26 0
3	52	21	63.86	5 847	5 847	5 847	*5 847*	5 794	5 793	5 794	*5.7937*	53 3
4	28	7	40.00	6 603	6 604	6 604	*6 6037*	6 584	6 585	6 585	*6 5847*	19.0
5	40	3	40.00	5 792	5 791	5 792	*5 7917*	5 784	5 785	5 783	*5 784*	7.70
6	52	21	16.24	4 675	4 676	4 676	*4 6757*	4 648	4 649	4 648	*4 6483*	27.4
7	40	14	40.00	5 786	5 786	5 785	*5.7857*	5 766	5 765	5 765	*5 7653*	20.4
8	40	14	40.00	5 750	5 750	5 750	*5 750*	5 724	5 725	5 725	*5.7247*	25.3
9	52	7	63.86	6 273	6 274	6 273	*6.2733*	6 252	6 253	6 252	*6 2523*	21.0
10	20	14	40.00	5 463	5 461	5 463	*5 4623*	5 458	5 457	5 458	*5 4577*	4 60
11	28	21	16.24	4 346	4 346	4 347	*4.3463*	4 331	4 331	4 331	*4 331*	15.3
12	40	14	80.00	5 898	5 897	5 897	*5 8973*	5 735	5 735	5 736	*5 7353*	38 0
13	40	25	40.00	5 773	5 772	5 773	*5.7727*	5 860	5 859	5 859	*5.8593*	37.4
14	40	14	40.00	5 291	5 292	5 292	*5 2917*	5 269	5 268	5 269	*5 2687*	23.0
15	40	14	40.00	5 518	5 518	5 518	*5.518*	5 492	5 491	5 492	*5 4917*	26.3
16	40	14	40.00	5 631	5 632	5 631	*5.6313*	5 608	5 609	5 608	*5.6083*	23.0
17	60	14	40.00	5 706	5 707	5 706	*5 7063*	5 667	5 668	5 668	*5.6677*	38.6
18	40	14	00.00	4 869	4 868	4 868	*4 8683*	4 858	4 858	4 858	*4 858*	10.3
19	40	14	40.00	4 358	4 357	4 357	*4 3573*	4 337	4 338	4 338	*4.3377*	19.6
20	52	7	16.24	4 971	4 972	4 972	*4 9717*	4 958	4 959	4 959	*4 9587*	13.0

Table 3.5 : Material Removal measurement (Aluminium)

EXPT NO	P bars	N cycles	A %	WEIGHT BEFORE MACHINING (gm)				WEIGHT AFTER MACHINING (gm)				MR (mg.)
				1	2	3	avg	1	2	3	avg.	
1	28	7	16.24	1 768	1 768	1 767	*1 7677*	1 763	1 761	1 762	*1 762*	5.70
2	28	21	63 86	2 267	2 266	2 267	*2 2667*	2 256	2 256	2 255	*2 2557*	11.00
3	52	21	63.86	2 254	2 256	2 254	*2 2547*	2 228	2 227	2 227	*2 2273*	27.40
4	28	7	40.00	2 267	2 267	2 266	*2 2667*	2 254	2 255	2 254	*2 2543*	12.40
5	40	3	40.00	2 139	2 140	2 140	*2 1397*	2 135	2 136	2 135	*2 1353*	4.40
6	52	21	16.24	1 759	1 760	1 760	*1 7597*	1 745	1 744	1 744	*1.7443*	15 40
7	40	14	40.00	2 050	2 049	2 049	*2.0493*	2 033	2 033	2 032	*2 0327*	16.60
8	40	14	40.00	2 102	2 102	2 102	*2 102*	2 083	2 083	2 083	*2.083*	19.00
9	52	7	63.86	2 182	2 181	2 181	*2 1813*	2 167	2 167	2 166	*2 1667*	14 60
10	20	14	40.00	2 158	2 157	2 158	*2 1577*	2 153	2 152	2 153	*2 1537*	5 00
11	28	21	16.24	1 759	1 758	1 759	*1.7587*	1 751	1 750	1 751	*1.7507*	8 00
12	40	14	80.00	1 700	1 700	1 700	*1 700*	1 670	1 670	1 669	*1 6697*	30.30
13	40	25	40.00	1 995	1 996	1 996	*1 9957*	1 973	1 973	1 973	*1.973*	22 70
14	40	14	40.00	2 042	2 043	2 042	*2 0423*	2 028	2 029	2 028	*2 0283*	14 00
15	40	14	40.00	2 055	2 055	2 056	*2 0553*	2 040	2 039	2 040	*2 0397*	15.60
16	40	14	40.00	2 164	2 163	2 164	*2 1637*	2 149	2 148	2 149	*2 1487*	15.00
17	60	14	40.00	2 044	2 043	2 045	*2 044*	2 023	2 024	2 023	*2 0233*	20.70
18	40	14	00.00	1 432	1 431	1 432	*1 4313*	1 426	1 425	1 425	*1 4253*	6.00
19	40	14	40.00	2 126	2 125	2 125	*2 1253*	2 112	2 113	2 112	*2 1123*	13.00
20	52	7	16.24	1 731	1 729	1 730	*1 730*	1 723	1 724	1 723	*1 7233*	6.70

Expt No	P bars	N cycles	V cc	Before Machining						After Machining					
				Ra (μm)	avg.	Rymax (μm)	avg	Rtm (μm)	avg.	Ra (μm)	avg.	Rymax (μm)	avg	Rtm (μm)	avg
1	28	7	16 24	0 91	*0 73*	8 25	**5.42**	3 23	**3 44**	1 09	*0 88*	6 72	**5.94**	5 04	**4.70**
				0 76		5 98		3 93		0 87		6 56		5 15	
				0 44		3 43		2 47		0 59		4 18		3 32	
				0 48		3 17		3 09		0 94		6 44		5 47	
				1 07		6 43		4 49		0 89		5 79		4 53	
2	28	21	63 86	1 80	*1 90*	8 16	**15 5**	6 61	**8 89**	0 61	*0 72*	4 27	**5 21**	3 43	**3 97**
				2 01		20 68		9 15		0 86		5 26		4 12	
				1 92		19 73		10 3		0 74		5 47		4 23	
				1 77		10 49		7 52		0 65		5 25		3 98	
				1 98		18 02		10 8		0 73		5 79		4 07	
3	52	21	63.86	1 33	*1 45*	7 80	**9 03**	7 20	**6.55**	0 87	*0 93*	5 26	**6 23**	4 81	**5.08**
				1 37		7047		5 30		0 93		5 59		4 72	
				1 52		9 00		6 75		1 02		6 87		5 14	
				1 52		10 43		6 56		1 04		7 11		5 64	
				1 49		10 43		6 95		0 80		6 30		5 08	
4	28	7	40.00	1 56	*1.69*	8.73	**10.9**	6 24	**6.67**	0 80	*0 77*	5 27	**4 94**	4 78	**4.34**
				1 75		11 74		6 51		0 83		5 39		4 49	
				1 64		8 94		7 62		0 81		4 81		4 38	
				1 90		13 88		5 39		0 78		4 99		4 22	
				1 62		11 42		7 60		0 64		4 22		3 83	
5	40	3	40.00	0 40	*0.55*	3 78	**5.19**	3 06	**3 05**	0 80	*0 92*	5 66	**6 64**	4 96	**5.20**
				0 63		5 31		3 53		1 06		7 73		5 66	
				0 42		2 53		1 97		1 10		6 76		5 11	
				0 78		9 58		4 13		0 84		6 20		5 08	
				0 52		4 77		2 58		0 82		6 87		5 18	
6	52	21	16.24	0 71	*0 89*	4 38	**6.48**	2 29	**4.14**	0 88	*0 92*	6 27	**6.17**	4 29	**4.58**
				0 68		4 38		3 49		1 05		7 84		8 14	
				0 60		6 42		3 80		0 65		4 71		4 11	
				0 68		4 88		3 49		0 94		5 52		4 78	
				1 78		12 35		7 61		1 08		6 49		5 68	
7	40	14	40.00	0 49	*0.68*	4 72	**5.07**	2 46	**3.11**	0 90	*1 01*	6 10	**7 24**	4 92	**5.37**
				0 92		7 14		3 77		1 39		11 8		6 60	
				0 93		4 70		3 76		0 92		6 19		5 24	
				0 52		4 73		2 58		0 77		5 04		4 94	

				0 61		1 08		2 99		1 09		7 03		5 15	
[illegible]	52	7	40 00	1 34	*1 29*	5 92	6 65	4 56	**4.71**	1 08	*1 04*	6 62	**5.68**	4 96	**4.68**
				1 26		6 24		4 14		0 89		4 30		3 96	
				1 37		7 78		5 08		1 14		5 68		4 80	
				1 76		7 68		4 60		1 06		6 35		5 09	
				1 20		5 65		5 17		1 04		5 46		4 61	
9	52	7	63 86	1 46	*1 37*	12 25	9 57	6 02	**5.68**	0 65	*0 68*	4 38	**4 89**	3 86	**4.12**
				1 41		8 99		5 47		0 71		5 06		4 08	
				1 38		9 14		5 72		0 64		4 90		4 16	
				1 28		8 20		5 26		0 72		5 09		4 38	
				1 32		9 26		5 92		0 69		5 00		4 10	
10	20	14	40.00	0 59	*0 59*	3 64	**4 67**	2 81	**3.27**	0 54	*0 68*	4 04	**5.03**	3 10	**4.16**
				0 47		4 14		2 45		0 75		5 11		4 26	
				0 75		5 06		3 48		0 57		3 34		3 11	
				0 64		6 42		4 61		0 69		5 95		4 40	
				0 53		4 08		2 99		0 86		6 69		5 94	
11	28	21	16 24	1 34	*1.28*	7 41	**6.56**	5 43	**5.14**	1 42	*1 36*	10 0	**10.0**	6 19	**5.93**
				1 56		7 50		7 54		1 09		6 43		5 36	
				1 18		4 65		3 54		1 24		8 66		5 77	
				1 07		6 47		4 65		1 07		9 71		4 69	
				1 24		6 79		4.54		1 96		15 2		7 65	
12	40	14	80.00	1 90	*1 48*	21 73	**11.1**	8 41	**6.42**	1 16	*1.64*	6 87	**8.16**	5 47	**6.41**
				1 23		8 01		5 73		1 68		8 80		6 61	
				1 56		15 71		6 50		1 89		8 42		6 77	
				1 36		11 47		6 54		1 57		8 01		6 08	
				1 37		6 72		4 93		1 92		8 62		7 13	
13	40	25	40 00	1 33	*1.08*	7 48	**6.43**	5 73	**5.60**	1 01	*0 78*	6 56	**5.81**	5 30	**4.54**
				0 94		7 17		3 68		0 96		6 63		4 99	
				0 74		3 86		4 32		0 70		5 65		4 26	
				1 04		5 83		4 72		0 56		5 16		3 99	
				1 37		7 83		9 56		0 68		5 05		4 15	
14	40	14	40.00	0 95	*0 69*	9 91	**6.20**	3 82	**3.34**	1 30	*1 00*	8 38	**7 13**	6 72	**5.15**
				0 41		2 21		2 87		1 02		8 45		4 73	
				0 56		2 53		1 91		0 69		5 28		4 17	
				0 91		12 20		5 03		1 06		8 06		4 99	
				0 64		4 14		3 06		0 95		5 50		5 14	
15	40	14	40.00	0 68	*0.62*	2 90	**4.51**	2 57	**3.04**	0 87	*0 79*	5 24	**6.03**	4 46	**4.46**
				0 60		8 75		4 01		1 00		7 73		4 98	
				0 53		4 06		3 14		0 76		4 93		4 28	
				0 71		3 35		2 47		0 73		6 45		4 56	
				0 58		3.48		3 00		0 57		5 79		4 01	

[illegible]	40	14	40 00	2 28	*1 82*	11 89	**8 94**	8 20	**6 96**	1 30	*1 23*	6 56	**5 52**	4 95	**5 08**
				1 00		11 13		7 96		1 25		6 77		5 27	
				1 82		7 64		6 65		1 31		7 08		5 52	
				1 13		5 06		4 53		1 05		7 17		4 94	
				1 65		8 96		7 57		1 25		5 49		4 33	
[illegible]	60	14	40 00	[illegible]	*0 96*	7 70	**8 10**	2 50	**4 82**	0 99	*0 91*	6 39	**6 39**	5 17	**5.06**
				0 82		5 51		6 61		1 09		6 20		5 45	
				0 99		5 94		4 38		0 74		7 38		4 82	
				1 13		4 81		6 28		0 84		5 18		4 88	
				1 15		5 55		4 31		0 89		6 81		4 96	
18	40	14	00 00	1 25	*1 01*	7 70	**5 90**	5 19	**4.22**	1 52	*1 51*	9 88	**8.04**	7 45	**6 64**
				0 92		5 54		3 66		1 64		8 68		6 68	
				0 94		5 94		4 16		1 56		7 42		6 45	
				0 92		4 81		3 76		1 42		7 31		6 21	
				1 03		5 55		4 33		1 40		6 89		6 39	
19	40	14	40.00	1 33	*0 95*	7 52	**5 64**	5 79	**4.38**	1 40	*0 99*	9 08	**7.07**	6 42	**5.07**
				0 80		5 97		2 76		1 22		6 53		5 49	
				0 88		4 69		3 07		0 85		6 17		4 76	
				0 73		3 68		2 77		0 82		6 70		4 02	
				0 99		6 36		4 52		0 69		6 85		4 68	
20	52	7	16.24	1 56	*0.93*	6 49	**7.21**	5 40	**4.24**	1 43	*1 18*	10 1	**8.85**	6 17	**5.69**
				0 89		8 94		5 83		1 15		7 67		5 69	
				0 61		4 91		2 86		1 11		9 05		4 68	
				0 55		6 79		2 28		0 70		7 65		4 50	
				0 94		8 91		4 82		1 49		9 83		7 43	

Table 3.7 : Change in Surface Roughness (Brass)

EXPT NO	P bars	N cycles	A %	$\Delta R_a (\mu m)$	$\Delta R_{y\,max} (\mu m)$	$\Delta R_{tm} (\mu m)$
1	28	7	16.24	0 144	-0 518	1 260
2	28	21	63.86	-1 178	-10 276	-4 920
3	52	21	63.86	-0 514	-2 800	-1 474
4	28	7	40.00	-0 922	-6 006	-2 332
5	40	3	40.00	0 374	1 450	2 926
6	52	21	16.24	0 030	-0 316	0 442
7	40	14	40.00	0 338	2 164	2 258
8	40	14	40.00	-0 244	-0 972	-0 026
9	52	7	63.86	-0 688	-4 682	-1 562
10	20	14	40.00	0 086	0 338	0 894
11	28	21	16.24	0 078	3 436	0 792
12	40	14	80.00	0 160	-2 970	-0 01
13	40	25	40.00	-0 302	-0 624	-1 094
14	40	14	40.00	0 31	0 936	1 812
15	40	14	40.00	0 166	1 520	1 420
16	40	14	40.00	-0 584	-3 420	-1 142
17	60	14	40.00	-0 052	-1 710	0 240
18	40	14	00.00	0 496	2 136	2 416
19	40	14	40.00	0 05	1 422	0 692
20	52	7	16.24	0 248	1 644	1 456

Table 3 8 · Surface Roughness Measurement (Aluminium)

Expt No	P bars	N cycles	A %	Before Machining						After Machining					
				Ra (μm)		Rymax (μm)		Rtm (μm)		Ra (μm)		Rymax (μm)		Rtm (μm)	
					avg		avg.		avg.		avg		avg		avg.
1	28	7	16 24	1 67	*1 17*	11 17	7 15	2 57	**3 26**	0 91	*1 05*	6 19	5 83	5 40	**4.74**
				1 28		9 54		2 15		0 89		4 56		3 97	
				0 85		5 64		4 16		0 84		5 64		3 99	
				0 94		4 22		3 78		0 76		4 74		4 67	
				1 10		5 18		3 63		0 95		8 04		5 69	
2	28	21	63.86	0 88	*0 99*	13 24	9 77	6 68	**5.58**	1 60	***1.43***	10 8	**10 1**	7 53	**7.69**
				1 20		13 97		8 12		1 36		9 02		7 44	
				1 40		11 56		5 89		1 29		9 87		7 51	
				0 82		5 33		3 73		1 48		11 5		8 30	
				0 64		4 74		3 48		1 40		9 02		7 65	
3	52	21	63 86	0 99	*1 33*	14 62	**14.9**	6 36	**8.92**	1 78	*1 82*	10 9	**12.2**	8 52	**9 69**
				1 53		10 23		6 39		1 69		11 3		9 17	
				1 46		10 88		8 35		1 75		12 3		9 13	
				1 20		18 03		12 1		1 86		13 0		10 3	
				1 46		21 03		11 4		2 03		13 5		11 4	
4	28	7	40.00	0 66	*0 93*	6 54	**8.16**	4 06	**5.35**	1 82	*1 57*	11 5	**10.2**	10 8	**8.99**
				1 36		8 72		7 62		1 65		8 77		7 97	
				1 01		6 78		5 18		1 53		11 9		8 88	
				0 73		6 02		3 98		1 58		10 5		9 02	
				0 88		12 75		5 93		1 29		8 36		8 22	
5	40	3	40.00	0 96	*0 95*	4 96	**5.12**	3 68	**3.62**	1 40	*1 38*	9 50	**10.8**	8 70	**8.85**
				0 64		3 67		2 69		1 37		10 1		8 64	
				0 73		4 79		3 48		1 20		11 5		8 26	
				1 33		7 94		4 97		1 38		9 90		8 82	
				1 09		4 22		3 30		1 56		13 0		9 81	
6	52	21	16.24	1 14	*0 67*	5 95	**4.74**	4 31	**3.23**	1 34	*1.44*	12 0	**12.8**	10 0	**10.0**
				0 58		4.99		3 23		1 50		12 2		10 1	
				0 47		3 63		2 62		1 57		14 4		10 9	
				0 43		2 42		1 67		1 44		12 0		9 75	
				0 75		6 70		4 31		1 34		13 3		9 82	
7	40	14	40.00	2 03	*1.55*	30 48	**19.0**	11 3	**7.46**	1 30	*1.59*	9 58	**10.5**	9 04	**6.86**
				0 87		7 02		4 19		1 48		9 54		8 42	
				1 33		12 59		5 43		1 59		10 0		8 11	
				2 02		28 46		10 0		2 00		14 1		8 71	
				1 49		16 59		6 35		1 58		9 44		7 99	

	52	7	40 00	[illegible]	2 54	24 31	23.2	15 8	13 4	1 97	2 32	15 7	17 4	9 59	10 4
				[illegible]		18 43		13 6		2 42		18 6		10 5	
				[illegible]		29 02		15 2		2 17		19 1		10 7	
				2 15		24 40		11 3		2 35		18 0		11 2	
				[illegible]		20 03		10 9		2 69		15 9		9 96	
	52	7	63.86	[illegible]	0 91	5 73	5.26	4 50	3.24	1 47	1 77	10 4	9.17	8 38	8 77
				0 89		5 46		4 25		1 65		12 3		9 40	
				0 62		4 15		2 83		1 47		9 30		8 05	
				1 01		5 47		4 63		2 11		11 9		8 76	
				1 06		5 48		3 74		2 16		12 0		9 26	
10	20	14	40 00	0 71	0 64	6 55	4.69	3 55	2.98	0 87	0 85	8 15	6 97	5 18	5.28
				0 73		5 59		3 63		0 94		6 20		5 69	
				0 44		3 64		2 12		0 75		5 59		4 87	
				0 62		3 74		2 67		0 84		6 35		4 88	
				0 70		3 97		2 95		0 84		8 57		5 76	
11	28	21	16.24	0 79	0 65	11 60	6.06	5 39	3.49	0 86	1 01	5 05	5 98	5 47	4 44
				0 67		3 58		2 88		0 80		5 16		4 02	
				0 37		2 60		2 03		1 33		7 64		4 28	
				0 68		7 01		3 18		1 16		6 54		4 32	
				0 84		5 49		3 99		0 88		5 52		4 10	
12	40	14	80 00	0 40	0 56	2 33	4 36	1 81	2.91	1 95	1 90	12 3	11.4	10 9	9.55
				0 48		3 23		2 31		1 77		11 7		9 19	
				0 56		4 97		3 21		1 89		10 5		8 92	
				0 67		4 74		3 67		1 96		12 3		10 6	
				0 71		6 53		3 55		1 92		10 3		8 19	
13	40	25	40 00	0 94	0.73	4 48	4 70	3 04	2.95	1 48	1 67	10 1	11.8	8 93	9.15
				0 96		5 27		3 58		1 69		10 7		8 62	
				0 44		3 14		2 11		1 70		11 7		9 12	
				0 52		2 87		1 95		1 87		13 9		10 5	
				0 81		7 84		4 07		1 60		12 5		8 62	
14	40	14	40.00	1 83	1.26	30 70	11.4	9 12	4.84	1 47	1 51	13 3	11.1	9 50	8.86
				1 40		7 36		4 82		1 72		9 89		9 49	
				1 17		6 72		4 30		1 70		9 31		8 44	
				0 93		6 93		2 34		1 09		8 44		7 23	
				0 99		5 48		3 61		1 59		14 5		9 66	
15	40	14	40.00	0 52	0.82	4 88	7 99	3 15	4.52	1 83	1.61	12 7	11 1	9 49	9.14
				1 28		11 68		6 79		1 61		11 0		8 71	
				0 50		5 46		2 92		1 71		11 0		9 89	
				1 04		12 44		5 94		1 37		10 8		8 79	
				0 74		5 49		3 78		1 54		10 6		8 80	

16	40	14	40 00	[illegible]	*0 83*	7 09	**5.68**	4 71	**3.61**	1 28	*1 38*	8 86	**10.2**	7 82	**8.63**
				0 87		4 88		3 91		1 34		10 5		9 34	
				1 10		6 33		2 42		1 53		11 6		9 41	
				0 55		2 85		3 59		2 33		10 3		8 84	
				0 72		7 29		3 44		1 41		9 48		7 77	
17	60	14	40 00	0 70	*0 86*	3 03	**5 34**	2 75	**3 94**	1 69	*1 63*	9 21	**10 3**	7 89	**8.71**
				0 93		5 50		3 28		1 65		10 1		9 72	
				0 99		6 36		5 18		1 55		10 6		8 79	
				1 04		7 28		5 39		1 80		12 4		9 66	
				0 65		4 54		3 12		1 48		9 08		7 49	
18	40	14	00 00	1 08	*0 65*	3 99	**3 27**	2 76	**2 12**	2 53	*2 21*	12 5	**10.9**	9 20	**8 53**
				0 75		3 10		2 05		2 40		12 3		8 82	
				0 50		2 15		1 93		2 08		8 11		7 23	
				0 51		3 27		2 06		1 91		10 6		8 30	
				0 42		3 84		1 81		2 12		10 9		9 12	
19	40	14	40.00	2 31	*1 61*	21 34	**14.0**	12 9	**7.96**	1 70	*1 64*	12 4	**11.1**	9 26	**8 78**
				1 76		13 65		9 28		1 70		9 80		8 73	
				1 99		17 99		10 7		1 67		12 2		9 46	
				0 67		6 46		3 55		1 75		10 3		8 45	
				1 34		10 73		3 38		1 40		11 0		7 98	
20	52	7	16 24	0 71	*1.25*	6 86	**7.86**	2 36	**3.97**	1 37	*1 52*	9 71	**12.9**	8 07	**8 54**
				1 36		11 88		4 90		1 47		13 5		9 55	
				0 75		5 64		2 04		1 45		12 3		9 44	
				1 73		7 67		5 16		1 32		9 17		7 79	
				1 74		7 24		3 57		2 01		20 0		7 84	

Table 3.9 : Change in Surface Roughness (Aluminium)

EXPT NO.	P bars	N cycles	A %	$\Delta R_a (\mu m)$	$\Delta R_{ymax} (\mu m)$	$\Delta R_{tm} (\mu m)$
1	28	7	16.24	-0 1198	-1 3156	1 486
2	28	21	63.86	0 1366	0 288	2 106
3	52	21	63.86	0 494	-2 762	0 768
4	28	7	40 00	0 646	2 010	3 726
5	40	3	40.00	0 432	5 692	5 222
6	52	21	16.24	0 764	8 028	6 886
7	40	14	40.00	0 042	-8 492	-0 602
8	40	14	40.00	-0 216	-5 784	-2 998
9	52	7	63.86	0 858	3 914	5 528
10	20	14	40.00	0 208	2 274	2 292
11	28	21	16.24	0 354	-0 074	0 944
12	40	14	80.00	1 334	7 054	6 640
13	40	25	40.00	0 934	7 084	6 200
14	40	14	40 00	0 250	-0 366	4 026
15	40	14	40.00	0 796	3 146	4 620
16	40	14	40.00	0 550	4 474	5 0214
17	60	14	40.00	0 772	4 936	4 766
18	40	14	00.00	1 556	7 620	6 412
19	40	14	40.00	0 030	-2 90	0 820
20	52	7	16.24	0 276	5 092	4 572

Chapter - 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The effect of different process parameters such as extrusion pressure, No of cycles and percentage of passage area reduction on the material removal and surface finish is studied The results of above study are discussed in this chapter With the help of statistical response surface fitting technique, the data are analyzed and 3-D surfaces are plotted using GNUPLOT graphics package The effect of process parameters on the surface texture is also studied with the help of Scanning Electron Microscope (SEM)

4.2 RESPONSE SURFACE ANALYSIS

The equation of general quadratic response surface is of the form

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{11} x_1^2 + b_{22} x_2^2 + b_{33} x_3^2 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 \qquad (4\ 1)$$

where, Y response under study,

$b_0, b_1 \ldots, b_{23}$ = constants,

x_1, x_2 and x_3 = process variables

The quadratic response surface for each response is obtained by calculating constants $b_0, b_1 \ldots, b_{23}$ with the help of a computer program

4.3 MATERIAL REMOVAL

The effects of extrusion pressure, No of cycles and % passage area reduction on material removal of brass and aluminium are discussed below

- **Brass (Workpiece Material)**

From the responses of Table 3.4 the constants $b_0, b_1 \ldots\ldots\ldots, b_{23}$ are calculated and the following response surface equation is obtained for material removal :

$$y = 22.92 + 7.489x_1 + 8.029x_2 + 7.387x_3 - 0.410x_1^2 - 0.0740x_2^2 + 0.4917x_3^2$$
$$+4.2125x_1x_2 + 1.6875x_1x_3 + 2.362x_2x_3 \ldots\ldots\ldots (4.2)$$

To study the effects of extrusion pressure, No. of cycles and % passage area reduction on material removal, one of the variables is kept constant and response surfaces are obtained The response (in this case material removal) is plotted along Z-axis, the remaining two variables are shown in coded form on X - axis and Y-axis (see conversion table 3.2)

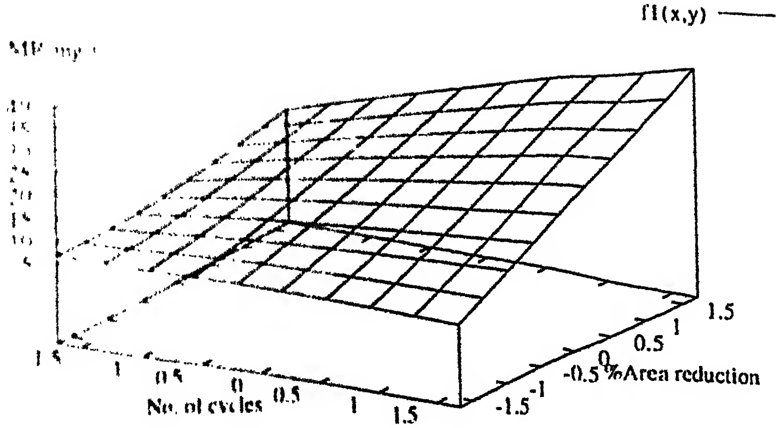
4.3.1 Effect of No. of cycles and % area reduction at different pressures

It is evident from Fig. 4.1(a) that the material removal increase at a faster rate as the % passage area reduction increases than the increase in number of cycles at constant pressure because as the extrusion passage area is reduced, the path of media flow is more restricted and the abrasive grains penetrate the surface to greater depth . Fig. 4.1(a),(b),(c) show that the amount of material removal increases with the pressure because with the increase in extrusion pressure the radial force on the abrasive particle increases which increases the depth of cut and hence the material removal increases.

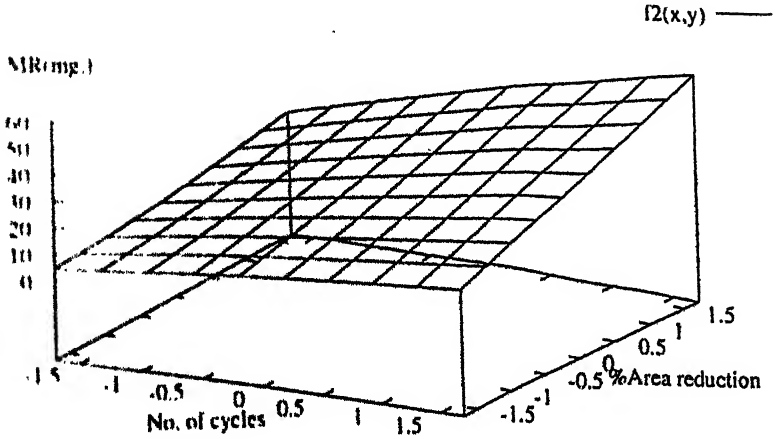
4.3.2 Effect of extrusion pressure and % area reduction at fixed no. of cycles :

Fig. 4.2 (a) shows that at fixed no. of cycles, the % passage area reduction is the dominating factor that effects the material removal. With the decrease in extrusion passage area the material removal increases. At greater % area reduction the effect of pressure on material removal increases. It is clear from Fig. 4.2 (a),(b),(c) that the material removal increases with the increase in number of cycles.

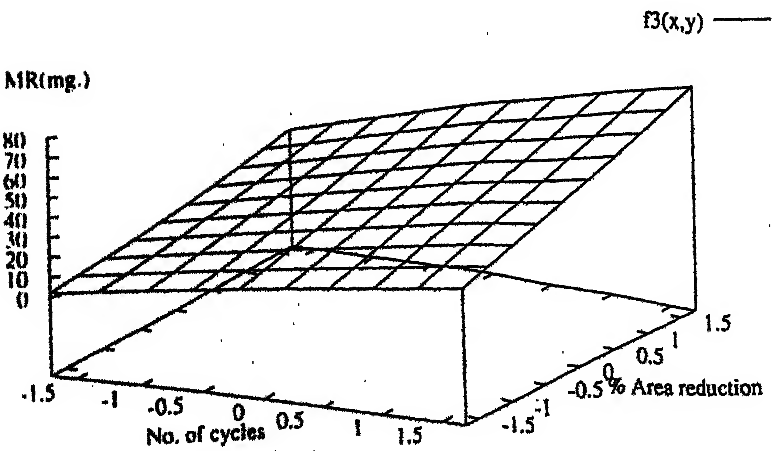
4.3.3 Effect of extrusion pressure and no. of cycles at constant passage area :



(a) Pressure = 28 bars

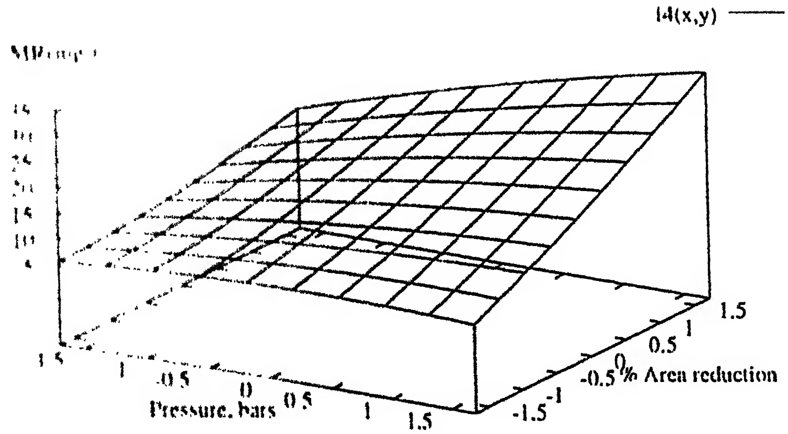


(b) Pressure = 40 bars

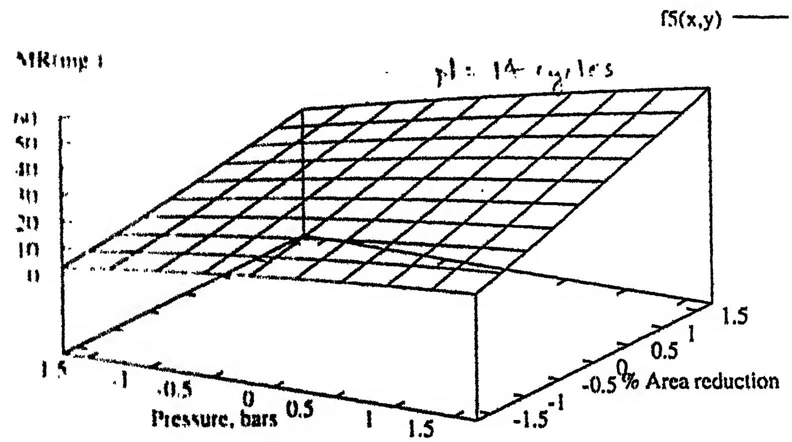


(c) Pressure = 52 bars

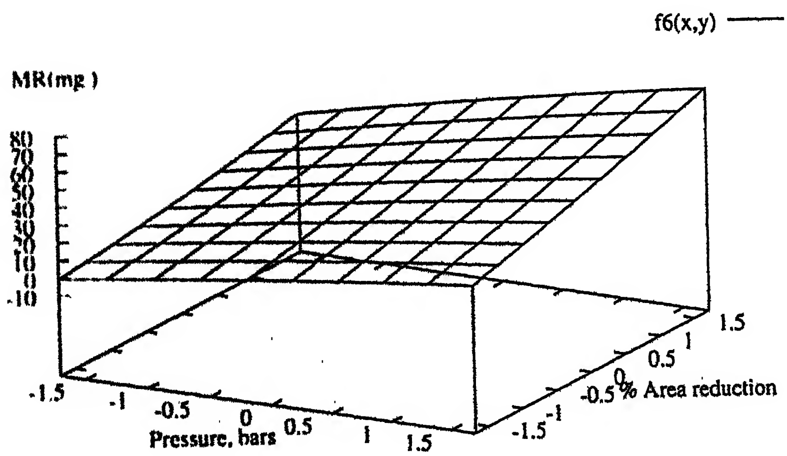
Fig. 4:1 : Effect of number of cycles and % passage area reduction at different pressures



(a) No. of cycles = 7



(b) No. of cycles = 14



(c) No. of cycles = 21

Fig 4.2 : Effect of extrusion pressure and % passage area reduction at fixed number of

Fig. 4.3 (a) shows that at constant extrusion passage area, with the increase in number of cycles the material removal increases. At greater passage area reduction the material removed is more for the same number of cycles (Fig. 4.3 (a),(b),(c)). The effect of extrusion pressure is significant at greater number of cycles.

- **Aluminium (Workpiece material)**

From the responses of Table 3 5 the constants $b_0, b_1, \ldots\ldots\ldots, b_{23}$ are calculated and the following response surface equation is obtained for material removal :

$$y = 15.6 + 3.91x_1 + 3.89x_2 + 5.16x_3 - 1.40x_1^2 - 1.15x_2^2 + 0.47x_3^2$$
$$+ 2.57x_1x_2 + 1.275x_1x_3 + 0.05x_2x_3 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

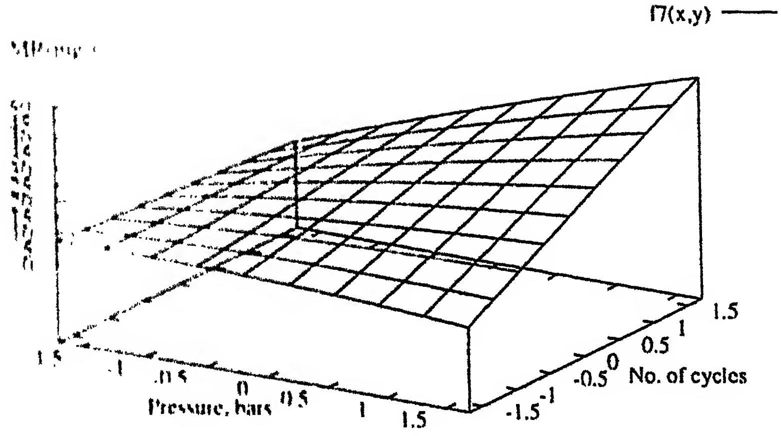
4.3.4 Effect of No. of cycles and % area reduction at constant pressure :

It is evident from Fig. 4.4(a) that the material removal increase at a faster rate as the % passage area reduction increases than the increase in number of cycles at constant pressure At some optimum number of cycles the material removal is maximum because initially, the surface has some irregularities, the material removal increases with the no. of cycles After some time the peaks and valleys get machined and the surface become somewhat flat than before, hence the material removal decreases after certain no. of cycles Fig. 4.4(a),(b),(c) shows that the amount of material removed increases with the extrusion pressure (reason is same as in case of brass).

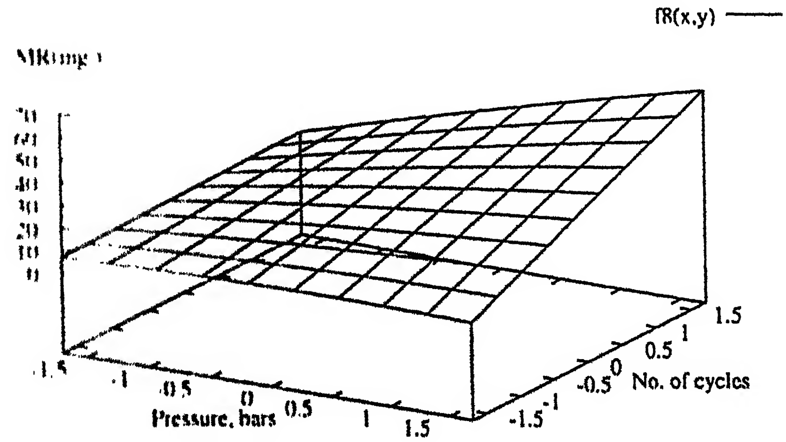
4.3.5 Effect of extrusion pressure and % area reduction at fixed no. of cycles :

Fig. 4.5 (a) shows that at fixed no. of cycles, the % passage area reduction is the dominating factor that effects the material removal. With the decrease in extrusion passage area the material removal increases for the same number of cycles. As the number of cycles increase the effect of pressure on material removal increases. It is clear from Fig. 4.5 (a),(b),(c) that the material removal increases with the increase in number of cycles.

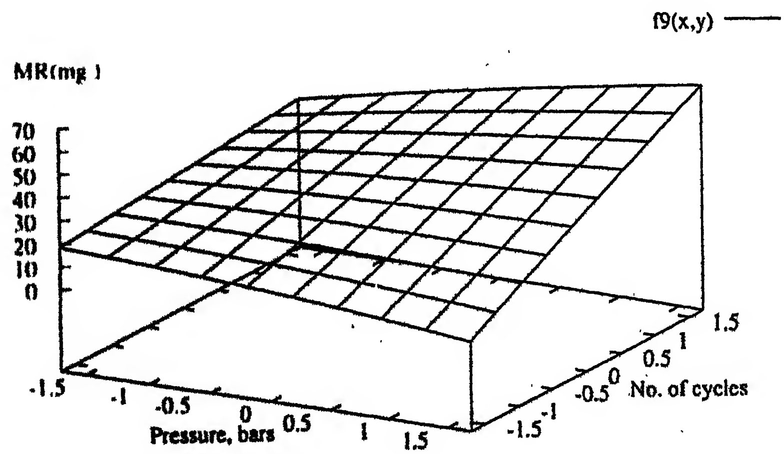
4.3.6 Effect of extrusion pressure and no. of cycles at constant passage



(a) % passage area reduction = 16.24 %

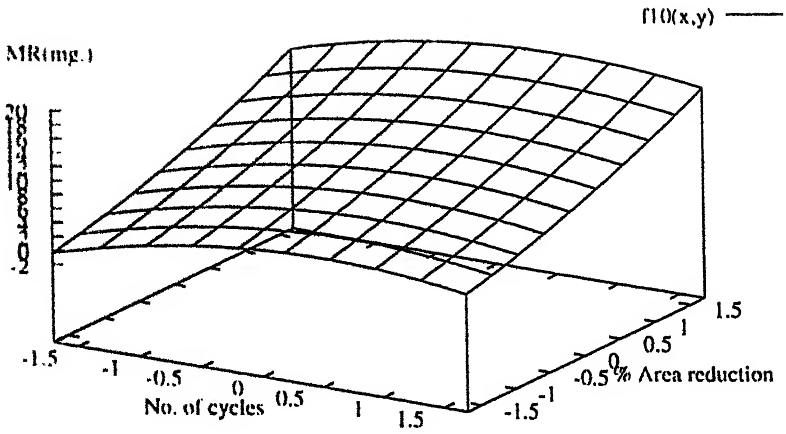


(b) % passage area reduction = 40.00 %

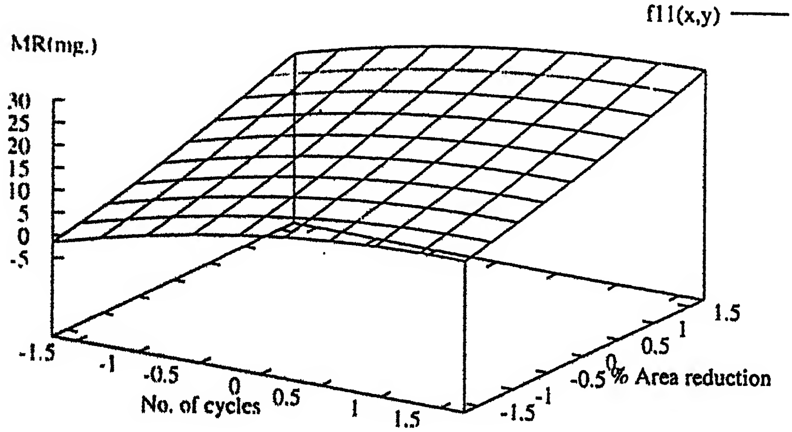


(c) % passage area reduction = 63.86 %

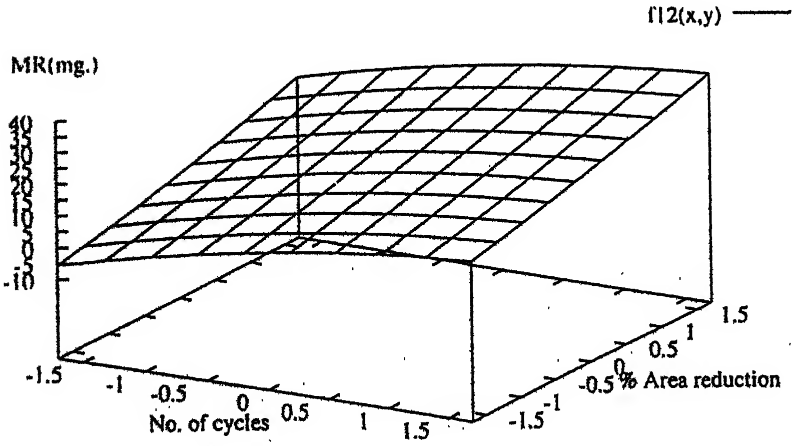
Fig 4.3 : Effect of extrusion pressure and number of cycles at different % passag



(a) Pressure = 28 bars

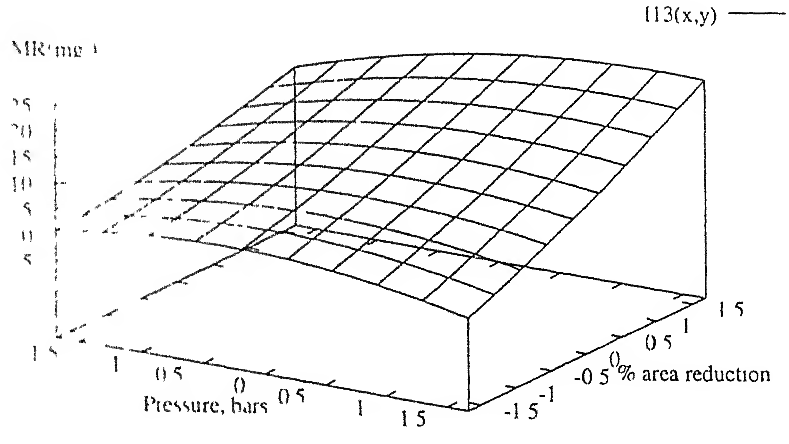


(b) Pressure = 40 bars

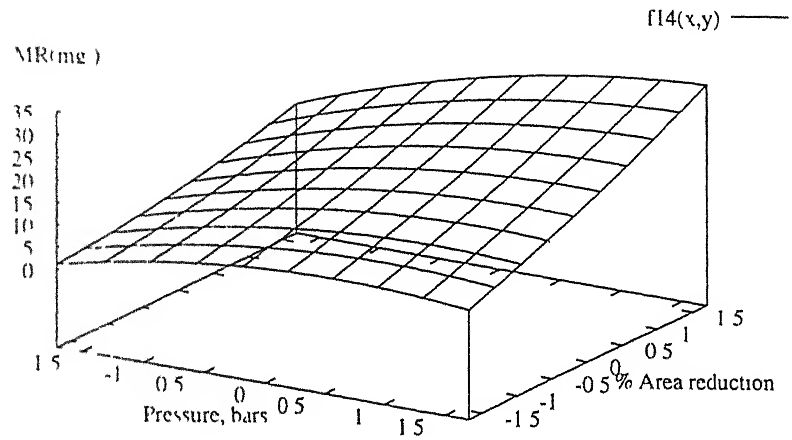


(c) Pressure = 52 bars

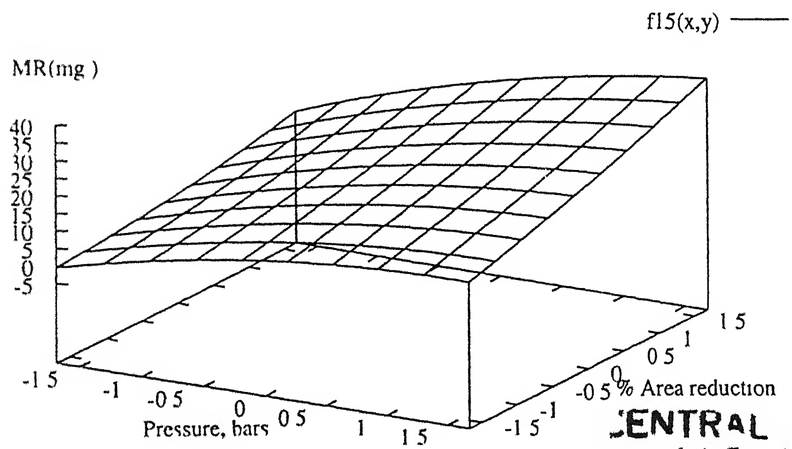
Fig. 4.4 : Effect of number of cycles and % passage area reduction at different pressures on material removal (Aluminium).



(a) No of cycles = 7



(b) No of cycles = 14



(c) No of cycles = 21

Fig 4 5 Effect of extrusion pressure and % passage area reduction at fixed number of

Fig 4 6 (a) shows that at constant extrusion passage area, with the increase in number of cycles the material removal increases The material removal decreases with pressure at low number of cycles For the same number of cycles the material removed increases with decrease in extrusion passage area (Fig 4 6 (a),(b),(c))

4.4 SURFACE FINISH

The effects of extrusion pressure, number of cycles and %passage area reduction on surface finish of brass and aluminium is discussed below

- **Brass**

From the responses (ΔRa) in Table 3 7 the constants b_0, b_1 $, b_{23}$ are calculated and the following response surface equation is obtained for change in Ra value

$$y = 0.022 + 0.053x_1 - 0.11x_2 - 0.319x_3 - 0.098x_1^2 - 0.092x_2^2 + 0.0116x_3^2$$
$$+ 0.0347x_1x_2 + 0.105x_1x_3 + 0.025x_2x_3 \qquad (4.4)$$

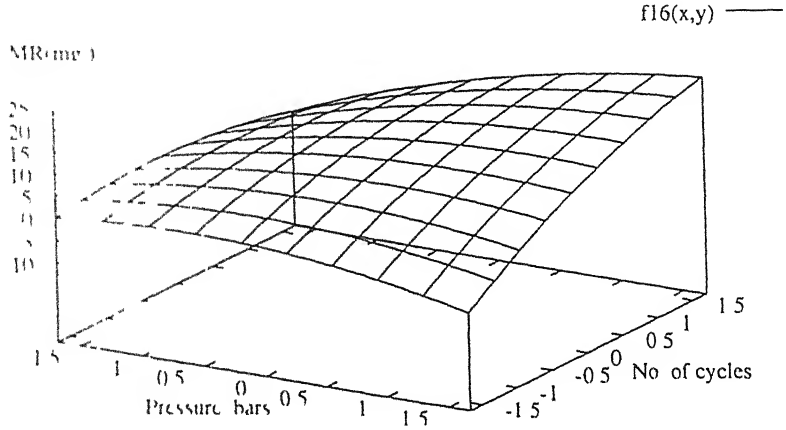
On substituting the values of variables x_1, x_2 and x_3 the response surfaces for change in Ra value are obtained

4.4.1 Effect of No. of cycles and % area reduction at constant pressure :

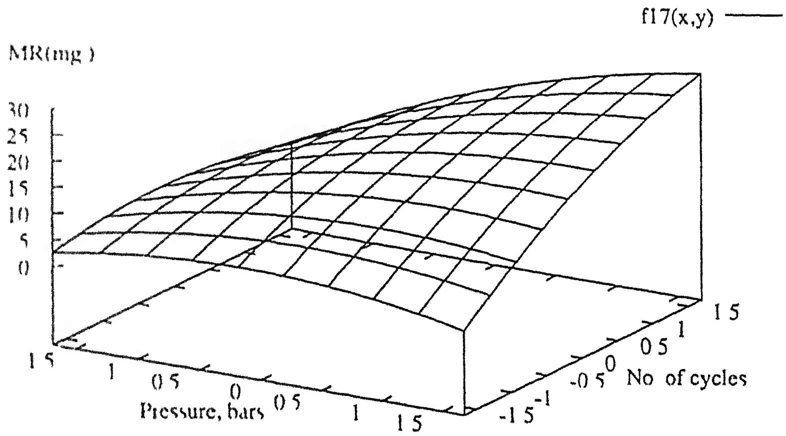
The Ra value in case of brass at constant pressure decreases with the increase in number of cycles and % passage area reduction (Fig 4 7 (a)) The surface finish at higher pressure improves as compared to low pressure for the same number of cycles (Fig 4 7(a),(b),(c))

4.4.2 Effect of extrusion pressure and % area reduction at fixed no. of cycles :

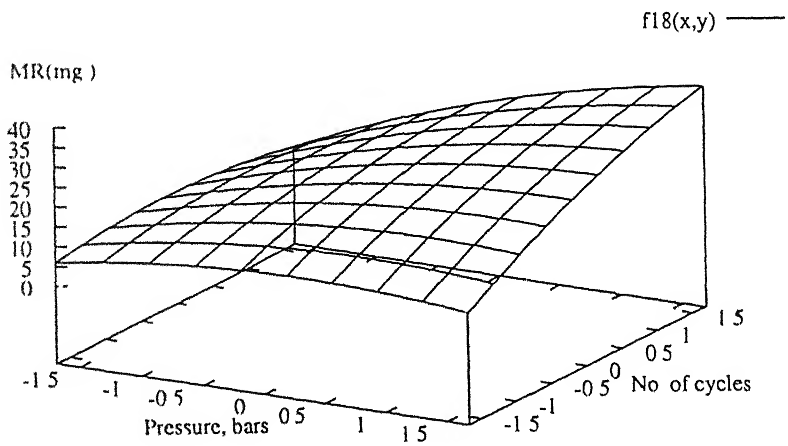
Fig 4 8 (a) shows that for constant number of cycles, the Ra value decreases as the extrusion pressure increases The % passage area reduction does not have much effect on Ra value With the increase in number of cycles (Fig 4 8 (a),(b),(c)) the surface finish improves after certain extrusion pressure At low pressure the surface roughness increases in case of brass



(a) % passage area reduction = 16 24 %

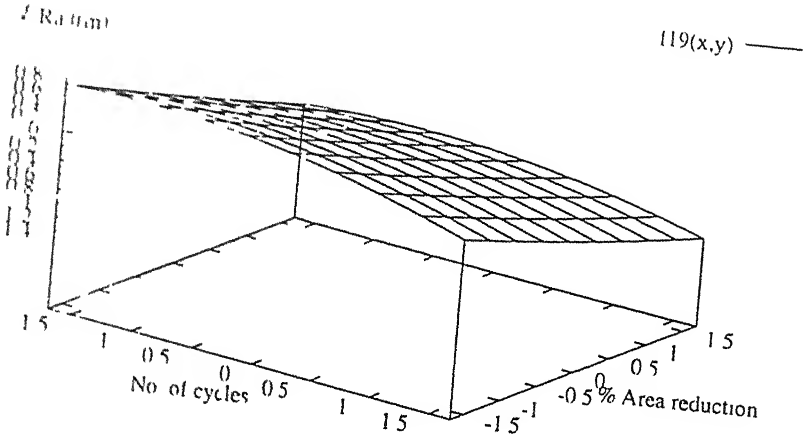


(b) % passage area reduction = 40 00 %

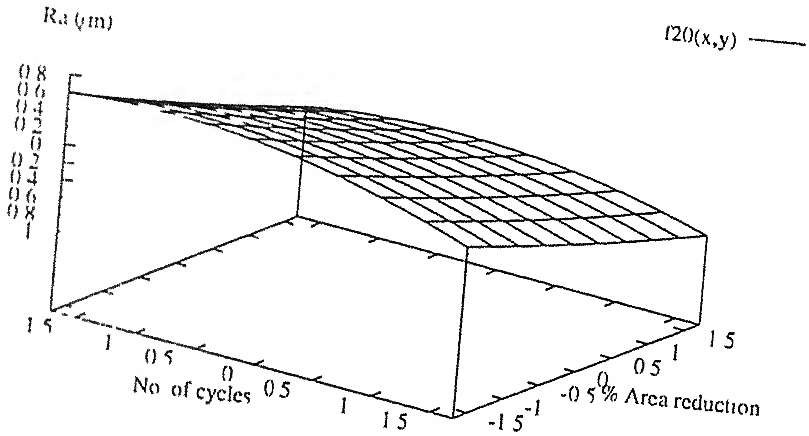


(c) % passage area reduction = 63 86 %

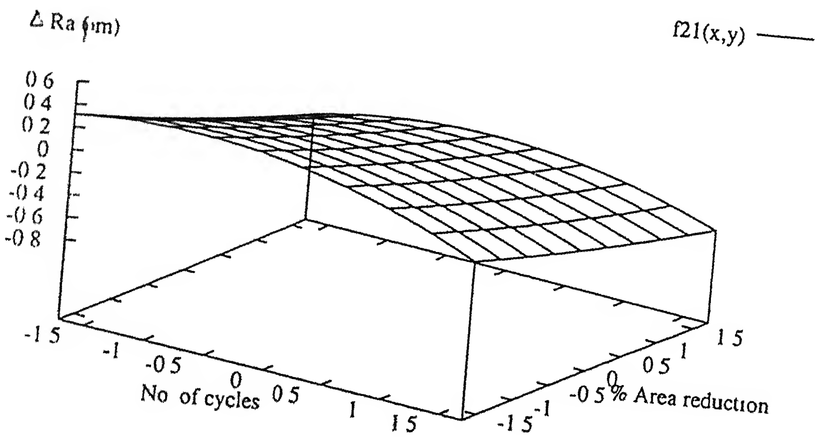
Fig 4 6 Effect of extrusion pressure and number of cycles at different % passage area reduction on material removal (Aluminium)



(a) Pressure = 28 bars

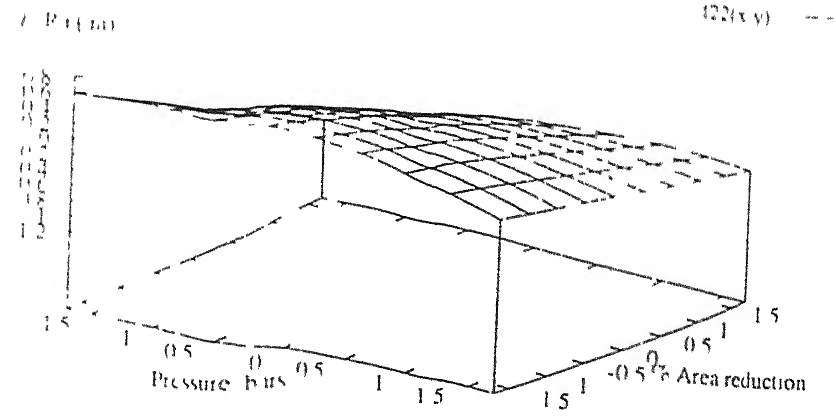


(b) Pressure = 40 bars

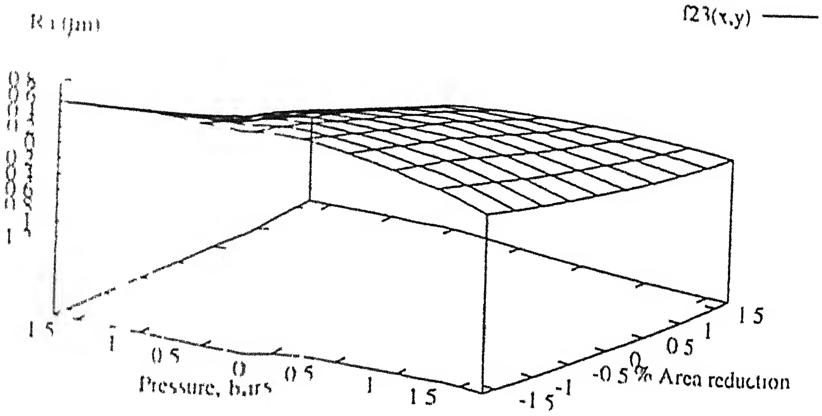


(c) Pressure = 52 bars

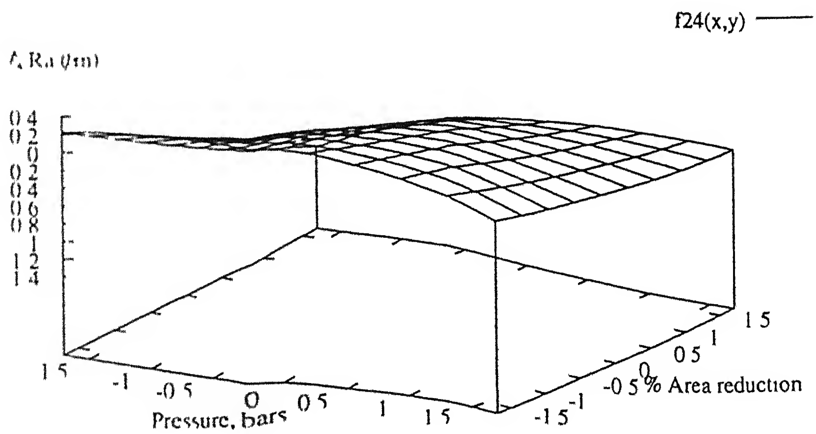
Fig 4 7 Effect of number of cycles and % passage area reduction at different pressures



(a) No of cycles = 7



(b) No of cycles = 14



(c) No of cycles = 21

Fig 4 8 Effect of extrusion pressure and % passage area reduction at fixed number of cycles on surface roughness (Brass)

4.4.3 Effect of extrusion pressure and no. of cycles at constant passage area :

At constant passage area, the surface roughness decreases at higher pressure and as the number of cycles increases the change in Ra value first increases to a maximum value then decreases(Fig 4 9) With the decrease in extrusion passage area the surface finish improves Fig 4 9 (c) shows that at greater % area reduction the change in Ra value decreases as extrusion pressure increases

- **Aluminium**

From the responses (ΔRa) in Table 3 9 the constants b_0, b_1 , b_{23} are calculated and the following response surface equation is obtained for change in Ra value

$$y = 0\,2574 + 0\,1701x_1 + 0\,0683x_2 + 0\,03566x_3 - 0\,01457x_1^2 + 0\,053678x_2^2 + 0\,32315x_3^2 + 0\,01995x_1x_2 - 0\,02955x_1x_3 - 0\,2294x_2x_3 \quad (4\,4)$$

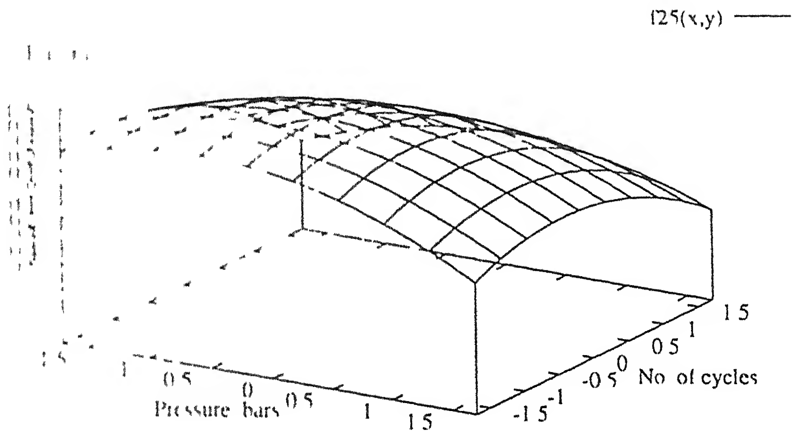
On substituting the values of variables x_1, x_2 and x_3 the response surfaces for change in Ra value are obtained

4.4.4 Effect of No. of cycles and % area reduction at different pressures

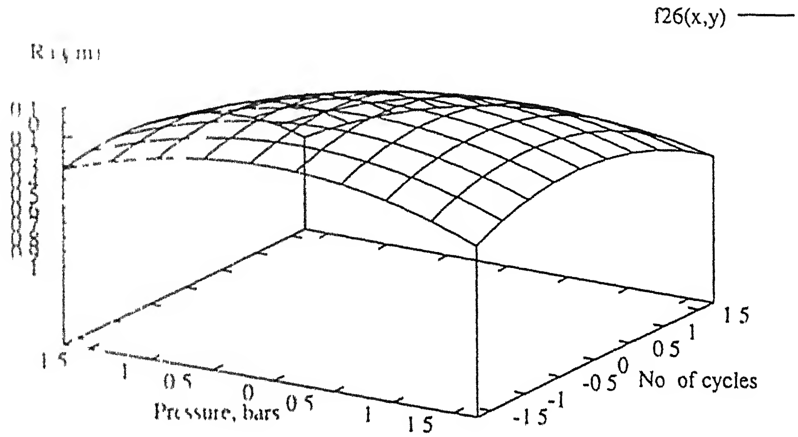
The change in Ra value in case of aluminium at constant pressure increases with the increase in number of cycles and decreases to a certain value of % passage area reduction and then increases (Fig 4 10 (a)) The surface roughness at higher pressure increases as compared to low pressure for the same number of cycles (Fig 4 10(a),(b),(c))

4.4.5 Effect of extrusion pressure and % area reduction at fixed no. of cycles :

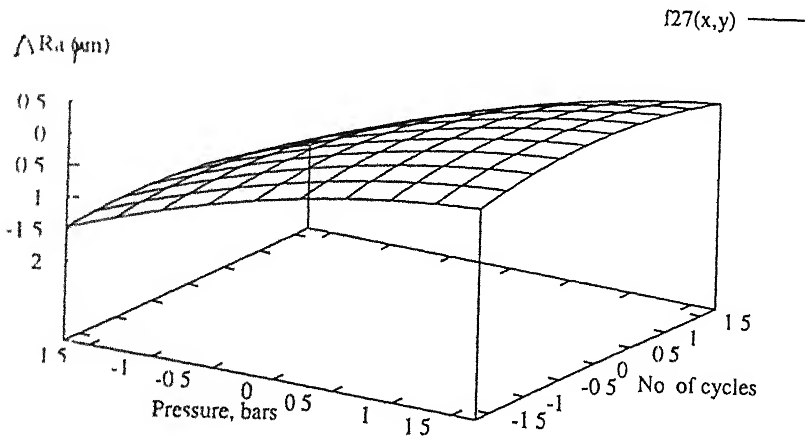
Fig 4 11 (a) shows that for constant number of cycles, the Ra value increases as the extrusion pressure increases The change in Ra value first decreases to a particular value of % passage area reduction then increases With the increase in number of cycles (Fig 4 11 (a),(b),(c)) the surface finish deteriorate to a greater extent The surface roughness increases with the extrusion pressure because in case of milled aluminium workpiece the initial surface finish is good, the abrasive grains penetrate to a greater depth



(a) % passage area reduction = 16 24 %

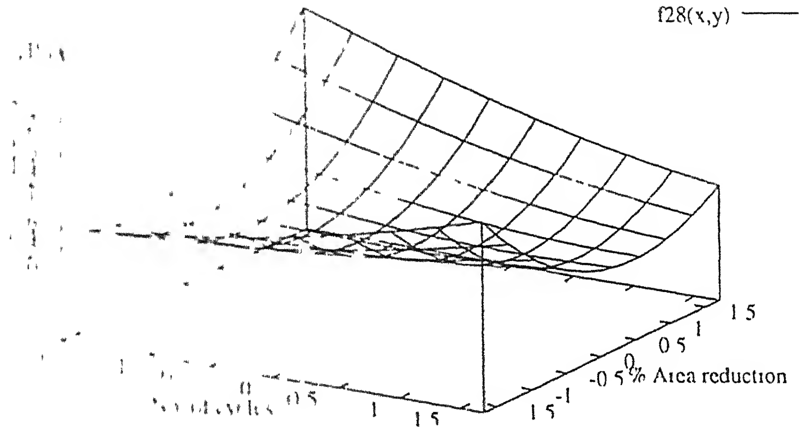


(b) % passage area reduction = 40 00 %

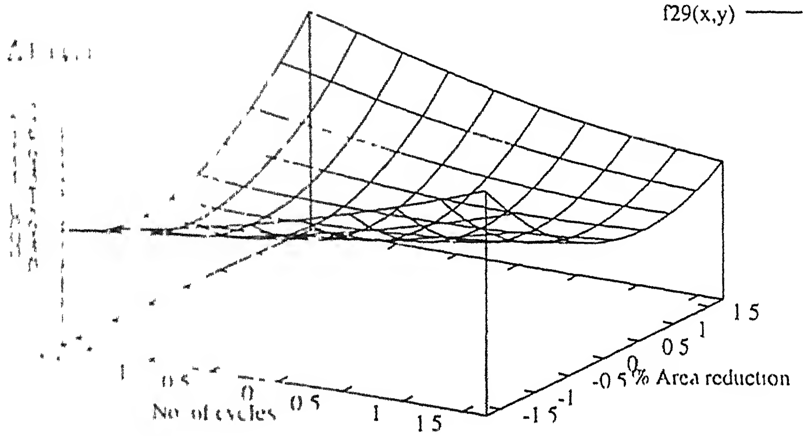


(c) % passage area reduction = 63 86 %

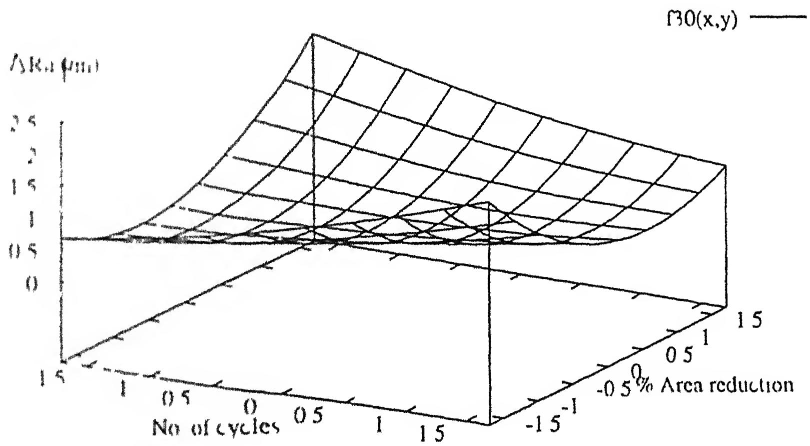
Fig 4 9 Effect of extrusion pressure and number of cycles at different % passage area reduction on surface roughness (Brass)



(a) Pressure = 28 bars

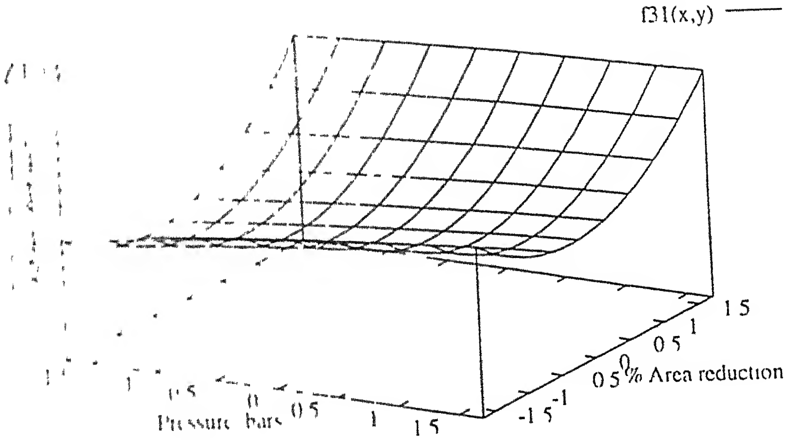


(b) Pressure = 40 bars

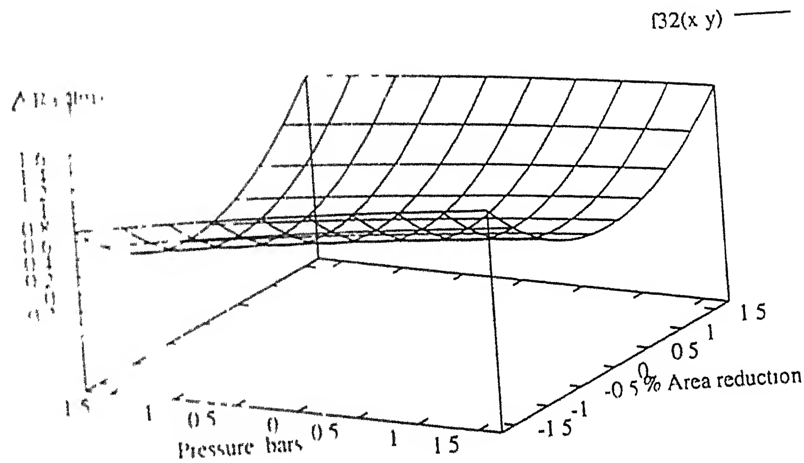


(c) Pressure = 52 bars

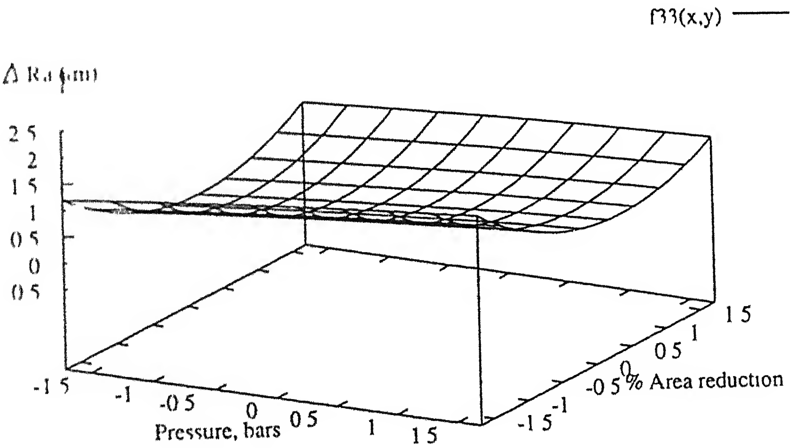
Fig 4 10 Effect of number of cycles and % passage area reduction at different pressures on surface roughness (Aluminium)



(a) No of cycles = 7



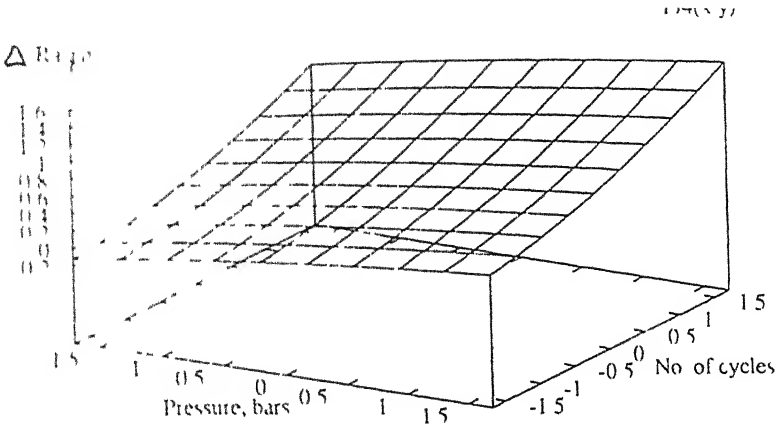
(b) No of cycles = 14



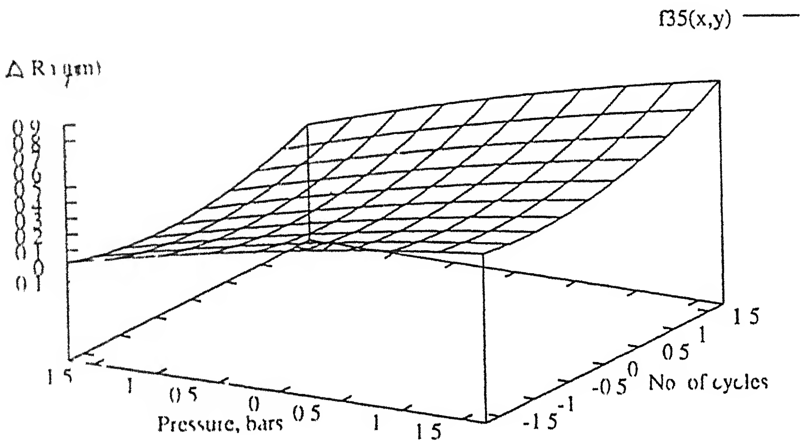
(c) No of cycles = 21

Fig 4 11 Effect of extrusion pressure and % passage area reduction at fixed number of

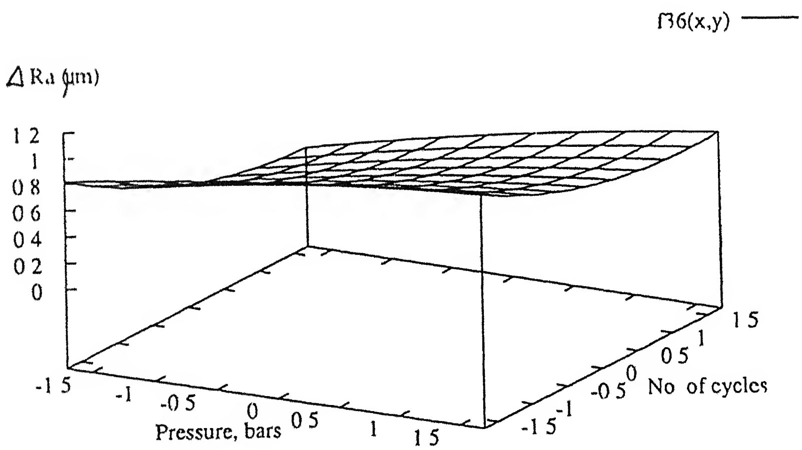
s (Aluminium)



(a) % passage area reduction = 16 24 %



(b) % passage area reduction = 40 00 %



(c) % passage area reduction = 63 86 %

Fig 4 12 Effect of extrusion pressure and number of cycles at different % passage area reduction on surface roughness (Aluminium)

at higher pressure and due to bigger grain size the abrasive marks are pronounced on the surface, thereby increasing the Ra value(Fig 4 13)

4.4.6 Effect of extrusion pressure and no. of cycles at constant passage area :

At constant passage area, the surface roughness increases with the extrusion pressure and as the number of cycles increases the change in Ra value increases (Fig 4 12) With the decrease in extrusion passage area the change in Ra value first decreases then increases

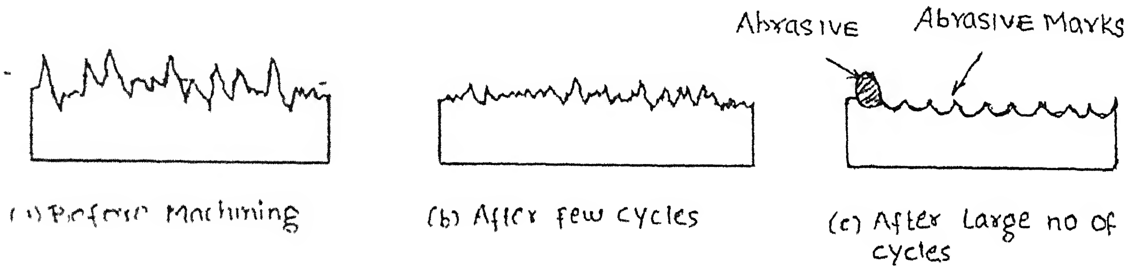
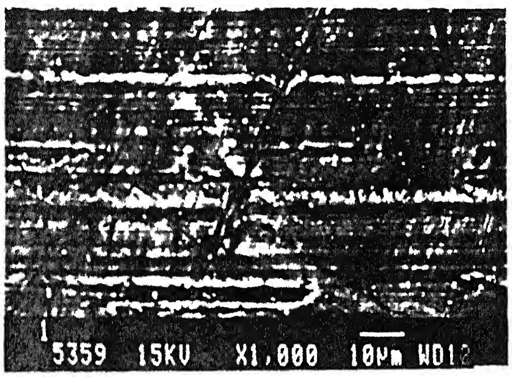


Fig 4 13 Increase in surface roughness due to bigger abrasive grain size

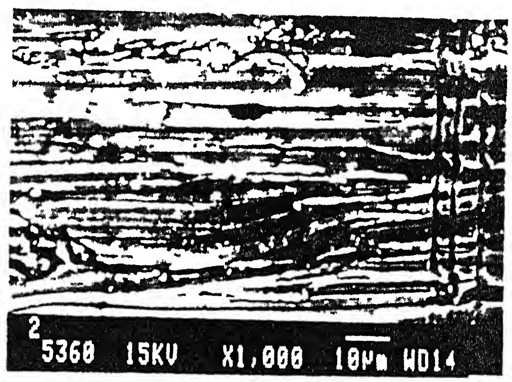
4.5 MACHINED SURFACE ANALYSIS

To understand the effects of various process parameters on the surface texture, specimens are observed under the Scanning Electron Microscope at higher magnification

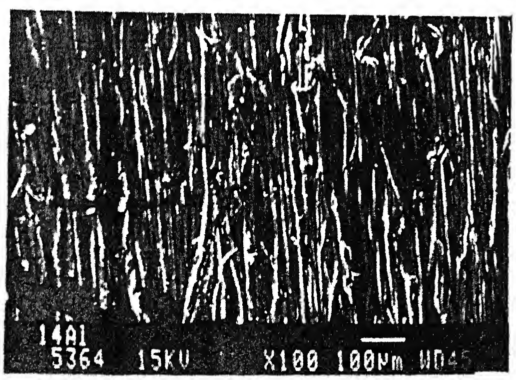
Fig 4 14 (a) is the micrograph of aluminium sample before machining After machining at 52 bar pressure for 21 cycles (Fig 4 14 (b)) the abrasive marks are clearly visible on the surface Parallel feed marks of the abrasive grains appear on the surface and deteriorate the surface finish Fig 4 14 (d) shows that the lumps of aluminium are formed and remain on the surface along the direction of media flow



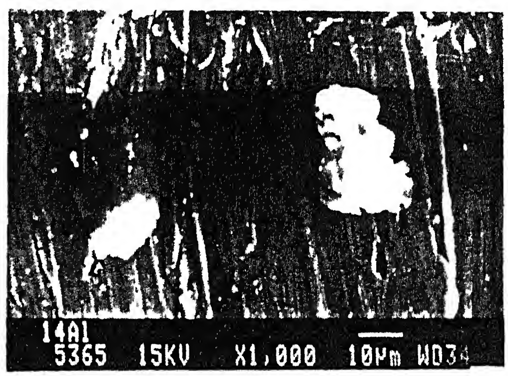
(a) Before machining



(b) After 21 cycles at 51 bar



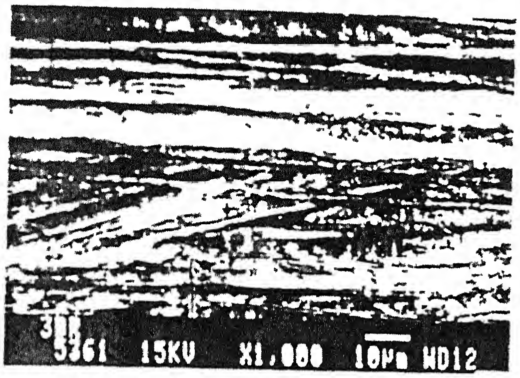
(c) After 14 cycles at 40 bar



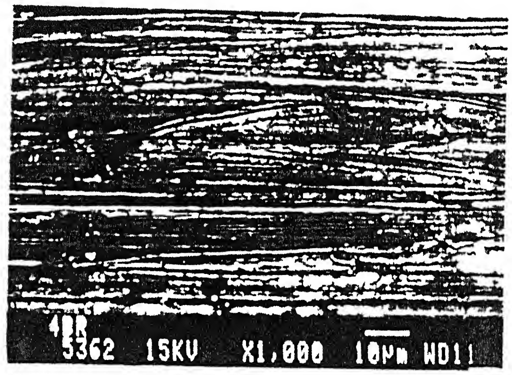
(d) Lumps of aluminium

Fig 4 14 Micrographs of Aluminium

Fig 4 15 (a) is the micrograph of brass sample before machining The abrasive marks in case of brass are not as deeper as in case of aluminium because brass is hard and brittle material, hence the surface roughness decreases after machining (Fig 4 15 (b)) There are no lumps of brass on the surface, only closely spaced abrasive marks are visible



(a) Before machining



(b) After 21 cycles at 28 bar

Fig 4 15 Micrographs of brass

Chapter - 5

CONCLUSIONS

5.1 CONCLUSIONS

In this study, abrasive flow machining (AFM) of brass and aluminium has been carried out to study the effects of various process parameters on material removal and surface roughness The following conclusions have been derived

1 The extrusion passage area effects the material removal significantly As passage area reduced, the material removal increases both in case of aluminium and brass

2 The material removal increases with the extrusion pressure and number of cycles

3 For the same extrusion pressure and number of cycles, thematerial removed is more in case of brass than the aluminium It is almost double in weight

4 At greater number of cycles, the effect of extrusion pressure on material removal is predominant

5 In case of aluminium, the material removed is maximum for a particular extrusion pressure at constant extrusion passage area

6 The surface roughness in case of brass decreases with the increase in number cycles, % passage area reduction and extrusion pressure

7 In case of ductile and soft material like aluminium, the surface roughness increases with the extrusion pressure and number of cycles The change in Ra value of the surface is minimum for a certain value of extrusion passage area It first decreases, reaches a minimum value and then increases (Fig 4 10)

8. The surface finish is mainly depends on the abrasive grain size The surface roughness in case of aluminium increases almost in all the experiments because if the abrasive grain size is greater than the initial Ra value then the initial peaks and valleys of the surface are replaced by the abrasive grain marks after machining(Fig 4 13) These marks are more deeper at higher extrusion pressure and after large number of cycles leaving more rough surface after machining

Chapter - 6

SCOPE FOR THE FUTURE WORK

6.1 SCOPE FOR THE FUTURE WORK

An attempt is made in the present work to understand the AFM to a certain extent but there are still some work that are to be carried out in the future

1 The following modifications are needed to be done in the present AFM set-up
   (i) A proper lifting mechanism is required to be added to the set-up
   (ii) For filling media in the media cylinder, the lower hydraulic cylinder should be replaced by the double acting hydraulic cylinder and connected suitably with the hydraulic power pack

2 The major constraints in the present work are the constant abrasive concentration and abrasive grain size Experiments are to be conducted in the future with different grain sizes and abrasive concentrations to understand their effects on the surface finish and material removal

3 Investigations in the area of media development are also required

4 The present set-up is flexible in handling different types of toolings Various types of tooling can be designed and experiments are conducted for different shapes of workpieces especially for finishing external complicated surfaces

5 The process has potential to remove a fine layer from the surface of harder materials This capability can be used for removing recast layer from the EDM'd surfaces

6 To have a better understanding of the process, optimization of the process parameters is necessary

7 It is required to study the effect of back pressure on the surface roughness and material removal

REFERENCES

1 Przyklenk K -"Abrasive flow machining - A process for surface finishing and deburring of workpiece with a complicated shape by means of an abrasive laden media", *ASME, New York, PED Vol 22, pp 101-110, 1986*

2 Rhoades L J - "Abrasive flow machining", *Manufacturing engineering, pp 75-78, Nov 1988*

3 Rhodes L J - "Abrasive flow machining and its uses", *Non-traditional machining conference proceedings, pp 111-120*

4 Kohut Tom - "Surface finishing with abrasive flow machining", *SME technical paper, pp 35-43, 1989*

5 Williams R E , Rajurkar K P , - "Stochastic modelling and analysis of abrasive flow machining", *Tran ASME, Journal of Engg for Ind, Vol 114, pp 74-81, Feb 1992*

6 Williams R E , and Rajurkar K P , - "Metal removal and surface finish characteristics in abrasive flow machining", *ASME, PED, Vol 38, pp 93-106, 1989*

7 Williams R E , Rajurkar K P , Rhodes L J - "Performance characteristics of abrasive flow machining", *SME technical paper, FC 89-806,1989*

8 Perry - "Abrasive flow machining - principles and practices", *Non-traditional machining conference proceedings, pp 121-127*

9 Rhodes L J - "Abrasive flow machining A case study", *Journal of material Processing technology, Vol 28, pp 107-116, 1991*

10 Studley N - "Abrasive flow machining" , *Yokohama international gas turbine congress, pp 311-315, 1991*

11 Loveless T R , Williams R E , Rajurkar K P - " A study of the effects of abrasive flow machining on various machined surfaces", *Journal of materials processing technology, Vol 47, pp 133-151, 1994*

12 Dubey A K , Shan H S - " Micromachining by flow of abrasives", *17th AIMTDR REC, Warangal, Jan 9-11, 1997*

13 William G Cochran and Gertrude M Cox - " Experimental Designs", second edition, *Asia publishing house, Bombay , pp 334-353*

14 Dudley A Pease - "Basic Fluid Power", *Prentice-Hall, Inc Englewood Cliffs, N J*

15 Ryder G H - " Solid Mechanics " , *ELBS , London*